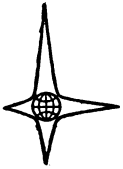
A. Shvarts

THE CODE OF LIFE



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ГОСУДАРСТВЕННОЕ ИЗДАТЕЛЬСТВО
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На английском языке

A. SHVARTS

The Code of Life

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Part One
Medicine Takes off

Know thyself! That is not so easy as it might seem. The human body has been examined from every angle, cut into thousands of different sections, investigated by X-rays and in anatomical specimens, yet it is still closed, waiting, as it were, for someone to say Open Sesame! To penetrate to the riches of the human body is probably more difficult than to reach a cherished treasure. But these days fact is often stranger than fancy. Much that only a short time ago seemed far beyond our reach has come closer, has been revealed. And the most amazing thing is that we no longer marvel at these new wonders. We take things in our stride as the common and the everyday. Yet the common at times becomes the wondrous.

Man has taken to outer space. The time will come and he will break ground in the unexplored depths of the living cell. The knowledge that he will extract from this "bottom" of life will be dearer to him than all the wealth of the world, for it will bring to the sick and ailing the greatest of all treasures—youth, strength, and health.

Surely the time is not far off when there will be doctors of health and not of disease. Then of the hundred-year-old we will read: "The untimely death of...." To be sure, this is the future, but it is already unfolding, heralded by the spectacular advances of recent years. This is the launching pad of medicine to which we now turn.

HEALING THE HEART

So many heartfelt words have been spoken about the human heart that hardly anything need be added. The heart is the centre of all joy and sadness, over the ages poets have dwelt on its whimsical turns, and the first song ever sung most likely came in a moment of deeply felt anguish.

But whereas the heart feeds the imagination with imponderable images, it supplies to the body very tangible red blood. Long before the infant comes to birth, while still in the womb of the mother, the first heartbeat signals the start of a new life, and that life comes to a standstill with the last heartbeat. Between these two contractions of the heart muscle lies a long—sometimes unfortunately a short—lifetime.

It has always been that if a person starts out in life with heart disease or if he contracts it later, he is doomed. Just a little while ago, the physician who made a diagnosis like that could not even imagine trying to eradicate the cause. The diagnosis virtually predetermined the outcome, and the sad thoughts of the doctor reverted time and again to the meagre facilities at his disposal to put off the inevitable end.

In a Vicious Circle

The heart is a great worker. It pumps thousands of litres of blood every day. And if it falls ill, nothing will come to its aid. Only drugs that give relief for an hour or two. The rest depends on the man himself.

Rheumatic excrescences on the heart valves stand invisibly in the path of the bloodstream. This places extra tension on the heart muscle, which now has to push the blood through a narrow scarred slit connecting the heart chambers. Unfortunately, this powerful heart pump cannot work on without end. There comes a day when it exhausts itself. Rheumatism has acquired ill fame as the ailment that "licks" the joints and "bites" the heart.

Not only infection, sometimes nature itself mercilessly deforms this tiny muscular organ. The opening of the vessel that carries used up venous blood to the lungs and to oxygen is sometimes congenitally narrowed to the size of a pea. This blood does not get rejuvenated; it by-passes the lungs, flowing into the aorta and once again to the vessels.

Then the heart muscle has to pump much more blood than usual in order to supply the organism with at least the minimal quantity of oxygen that life demands. But no matter how generous it expends its energy, the imperfection of the heart muscle permits the oxygen starvation to increase in all the tissues of the body.

The body is starving for lack of oxygen, while

the heart, thoroughly exhausted by murderous overwork and constant underoxidation loses its ability, day by day, to assuage this thirst. Itself faulty, vicious, it gets into a vicious circle. Such patients are rare, for they hardly ever live long enough to grow up.

There is no drug capable of widening the space between the adhering heart valves of the rheumatic. Nobody has yet conjured up powders that increase the bore of underdeveloped vessels. It would seem that nothing could save these doomed heart patients.

Yet a way out was found. And as so often occurs, it appeared where least expected.

Hope dawned on the day the ward of little patients living out their short lives was visited by a surgeon who dared to raise the scalpel over the beating heart of a child. The sharp edge of the scalpel brought life.

Although surgeons are often accused of trying to extend their dominion over more and more illnesses, the idea of surgery for the treatment of deformed heart conditions—even the tiniest operation on the heart—was long frowned on by many outstanding representatives of this branch of medicine. The knife of the surgeon that has so often come to the aid of the patient now seemed to lose courage. Nothing could make the surgeon touch the heart with needle or scalpel, not even a bullet wound or razor-blade cut, which meant death.

The medics, like lovers, have always viewed heart wounds as beyond treatment. When in the eighties of last century the noted St. Petersburg surgeon, Professor Filippov, first sutured the heart of a living dog, his experiments were viewed with the sceptical smiles of experts and the angry bewilderment of the ignorant. And there was good reason to doubt the success of such experiments, if such a virtuoso surgeon as Professor Theodor Billroth, of Vienna, in a bitter moment gave warning: the physician who dares sew the heart muscle, even if the patient is dying, will bring upon himself general contempt. Such was the opinion of one of Europe's best surgeons. For everyone this view had the force of law.

True, this was not to the liking of many doctors—this savage law that tied the hands of the surgeon in the very face of death. A man wounded in the heart died surrounded by physicians that could only watch his agony. No, not even the *ex cathedra anathema* of a famous scientist could hold up attempts to save a dying heart.

There were surgeons that thought differently. These "heretics" did not agree with the viewpoint of the law-givers, and they had weighty grounds for doing so. They knew very well that authority in science is the best and yet the very worst of all things. Many could still recall the times when surgeons of no less fame had come out against the use of ether as a pain-killer. "Operations without pain are a chimera," they contended without grounds. "The scalpel of the surgeon

and pain are inseparable," was the echo. Nevertheless, the killing of pain made inroads into all the operating theatres of the world and became one of the greatest boons of medicine.

Yet hardly fifteen years had passed when the Scotchman James Simpson, who had heroically defended anesthesia from fierce and unjust attacks, struck out against the Englishman Joseph Lister who got the remarkable idea of preventing suppuration of operational wounds by the use of a carbolic dressing.

This simple and great innovation was immediately taken up by surgeons everywhere, but it proved so alien to the mode of Simpson's scientific thinking that, in a temper, he compared the carbolic dressing technique to the savage medieval custom of immersing an amputated limb into boiling oil. Yet the ordinary carbolic acid used by Lister during operations saved patients from fatal blood poisoning that had been carrying off many thousands of lives every year.

In a word, the history of surgery did not promise a warm reception to heart operations, in fact to any radical innovation.

It would not be fair to think that surgeons were restrained solely by Billroth's warning. In those times every doctor realized that the words of this great maestro and scientist were not so much a warning as simply the bitter recognition of helplessness. Science had a long way to go yet before it would be able to offer surgery reliable techniques for curing the heart.

It moved along numerous little pathways from different directions converging gradually to the common goal.

Three Barriers

For a long time, one of the chief reasons for this "fear of the heart" that surgeons had was the fatal shock the patient experienced on the operation table as soon as the surgeon opened up the pleura to get at the large vessels. At that instant a sharp unbearable pain smashes into the brain from the sensitive nerves of the pleura. The storm of violent pain sensations slashes through the anesthesia and plunges into the central nervous system operating like a sudden brake. The central system loses control over the vitally important functions of the organism. The first warning signal of the onrushing catastrophe is the rapid fall in arterial pressure. In this tragic moment the blood pressure of the surgeon jumps just as fast as that of the patient falls.

Shock became a sort of sound barrier for intrathoracic surgery. Any further advancement depended on surmounting this barrier. Neither virtuoso operational techniques nor ideal cleanliness could scale this solid wall on the way to the heart. To eliminate it, new methods of killing pain had to be found that were more reliable than those used in the days of Pirogov and Simpson. This needed some serious thinking, for an effective anesthesia spelled success in the operation and often decided the fate of the patient.

The first thought was about a novocain blockade of the most sensitive zones of the pleura and nerve stems. What could be more intriguing than to block the stream of pain impulses to the brain and extinguish the pain at its very origin?

This was achieved only after the Soviet surgeons Nikolai Burdenko and Alexander Vishnevsky created excellent methods for anesthetizing tissues and interrupting the conductivity of nerves. Since then not only pain but even its subconscious reflex echoes were blocked where they originated. Shock retreated, but it was too early to celebrate victory. There was yet much to learn.

When the surgeon opened up the pleura he not only caused pain, but damaged the organism in such a way as to appear, at first sight, irreparable. Entering the pleural cavity, the air squashed flat the blebby pulp of the lung and pressed it to the mediastinum. Lacking pressurization, the lung collapsed like a pricked balloon.

Army surgeons in past years considered an open wound of the chest cavity tantamount to death. Only a miracle could save a soldier in whom a shell fragment had torn several ribs or broken the pleural sac. The doctor was helpless. And the patient's fate in the case of a wide-open pleural wound was the same whether he was in the trenches or in a perfectly sterilized all-white operation theatre. To save the heart, doctors had to cross this threshold as well. That is where the idea of controlled respiration originated.

Surgeons reach the patient's heart through the pleura. To do this, they invariably have to break the pressurization of the chamber that contains the lung. Deprived of its elastic protection, the lung succumbs completely to atmospheric pressure. A terrible complication sets in—open pneumothorax.

This new difficulty led doctors to think about the possibility of restoring the lost pressurization from within the lung. There was nothing very involved in the idea, engineers could resolve it with a simple device. But humans are more wonderfully built than machines. One thing was clear: before opening up the "gates" to the pleural cavity, a force had to be found capable of withstanding the inrush of air from without.

It took quite some time to find such a force. It came with the invention of an apparatus for intratracheal anesthesia, which enabled physicians to establish controlled respiration.

Now the accidental ceased to affect the course of an operation. Every contingency was provided for in advance. The surgeon inserted a rubber tube into the trachea and connected it up to the anesthetic equipment. He could then turn on the oxygen, carbon dioxide and narcotic gases as required. If necessary, the patient could live a certain time with his chest inactivated—the physician just switched it out of the respiratory act.

The old practitioner of Chekhov's time, round the turn of the century, would probably look in wonder and amazement at a modern operating

theatre. "What are you doing," he would cry, "that injection you've just given will paralyze the muscle system immediately. You'll kill him." And what would his terror be to find an actual lifeless, breathless body before him? His wonderment would mount as he saw that nobody was even trying to save the patient. No one seemed worried in the least, no frantic efforts were being made. The surgeon was calmly continuing the operation, the lungs had come to a halt, making it very convenient to work; the nurses readying instruments in absolute silence, and only the anesthetist peering intently into the face of the patient. From time to time he switches round to check the pointer of a special instrument which keeps tab on the amount of oxygen the organism is receiving. If the pointer goes just a tiny bit below the permissible level, the anesthetist delivers a stream of invigorating gas to the lungs. The oxygen spurts through the rubber tube into the trachea, from there into the bronchi, and then into the alveoli where the red blood corpuscles are avidly awaiting it. Here they load up with this invaluable food and hurry on to the brain, heart and muscles, to all organs and tissues of the body.

Then the doctor notices something wrong. No, it is not the oxygen. The patient has responded with his eye reflex. This means that deep down in the brain, consciousness is awakening. This is perhaps the only time when consciousness is detrimental to the patient. A swift twist of the wheel and narcotics are sent stream-

ing to the lungs. The doctor gradually builds up the flow putting the patient into a profound sleep, so deep at times that there is no need for a blockade of the extra-sensitive pleura. No matter how violent the pain signals it sends out, the brain remains dead to them, in deep sleep. The surgeon goes on calmly with his difficult job, he knows that the patient will not suffocate from lack of oxygen and he will not succumb to unbearable pain.

Thus medicine took one more difficult hurdle on the way to the heart.

Shock was conquered and banished from the operating room but there was still mortal danger due to intense bleeding, sudden retardation or stoppage of cardiac contractions and this compelled the surgeon to give up attempts to help patients that were doomed in such complications. A doctor cannot always risk a patient's life even in the name of saving it.

The new obstacle called for fresh explorations and new thinking. Hardly was one difficulty overcome than another, more complicated one, arose.

A pause in the heart beat, just a few minutes, but how important for the human being—beyond this lies the end of life. Heroic efforts can resuscitate the heart and get the blood pulsating in the arteries, making the lips rosy again, but the patient does not come to life. The brief lapse in blood circulation and respiration bring with them irreversible changes, the principal one being the death of the brain. The nerve cells

are the first victims of oxygen starvation, and no matter how the organism fights death, the struggle is decided in the first five or six minutes after the heart has stopped. Life prolongs itself for these few moments and then goes out for all time.

One minute earlier or one minute later—is there really any difference? To some it might seem to be bitter irony, but to physicians seeking ways to revive persons meeting sudden deaths, it is decisive. For if cardiac arrest did not signify instantaneous and invariable death of the whole organism, then the situation was not so hopeless after all. What needed to be done was to learn to restore blood circulation and breathing immediately. How the blood was to be pumped into the arteries, by the force of restored heart contractions or with the aid of some other pump, was solved later. What was clear at that point was that the cells of the central nervous system cannot wait, they must receive oxygen without fail, continually.

One of the first to grasp this indisputable truth was a young physician Fyodor Andreyev. At the start of the century he was already seeking ways and means. Andreyev knew that just recently Professor Aleksei Kulyabko had revived the heart of a corpse. But he had not succeeded in bringing the whole body back to life. This was what Andreyev did in 1913.

Ordinarily, blood is introduced into the veins and then spreads out through the maze of vessels, flowing round the body for some time before it

reaches the heart. This method was obviously not suitable for rapid resuscitation. Andreyev chose a shorter and better route. He pumped blood directly into the carotid artery of a killed dog. The blood flowed straight to the vessels of the heart and started it up again. Breathing was immediately restored and the dog came to life.

Of course, an experiment on an animal is only a biological model, and physicians were in no hurry to take this as an example for the clinic. However, Andreyev's method of intraarterial blood pumping was so simple and offered so many advantages that it served as a starting point for a whole series of attempts at resuscitating the human heart, and culminated in an unprecedented victory of life over death.

Cold—Enemy or Friend?

On their tortuous way to the heart scientists occasionally made astounding discoveries. What had always seemed the most bitter enemy of the patient, suddenly exhibited curative properties and became their ally in the struggle to save human life. Cold, which had always been on the bad list of physicians, suddenly attracted their attention.

Interesting observations of the hibernating habits of wild animals served as the starting point. Nature had good reason for creating this freak. The dormant state, hibernation, saves the inhabitants of the forests and fields during periods of food difficulties. It both relieves the

animals of daily search for food and appreciably economizes the accumulated summer supply.

During sleep, the temperature of the animal falls several degrees. This is attended by a reduction in food requirements, and oxygen; respiration is hardly perceptible. Life goes underground, as it were, saving its strength, yet does not cease completely for a single moment. Hibernating animals spend the whole winter on reduced rations, both food and oxygen, and come to full life again in the spring.

It was nature that suggested to physicians the idea of utilizing cold in operations on the heart, when oxygen starvation is particularly acutely felt. Artificially reducing the body temperature slows up the vital processes and for a time reconciles them to lack of oxygen.

This method is called hypothermia, or deep-freeze, and was at first enthusiastically received by surgeons. But unfortunately, cold is not only a disinterested friend of the patient and an ally of the doctor. It brings with it a number of unpleasant surprises.

An extremely grave complication due to artificial cooling of the body is fibrillation of the heart—waves of irregular heart convulsions which cannot always be halted by a powerful high-frequency current discharge.

Hypothermia radically reduces blood pressure and all physiological processes occurring in the body. This invariably affects the protective forces of the patient, which are already largely exhausted by the grave disruption of blood circulation.

And there are many other danger-fraught occurrences that dog the steps of the surgeon who makes use of the cooling technique. It was now clear that with hypothermia the physician did not have a cure-all. Far from it, there were fresh complications at every turn.

The deep-freeze technique is now resorted to when the risk of the operation far exceeds the dangers of hypothermia. Obviously, the reasonable thing is not to force the organism—at the expense of grave sacrifice—to oxygen starvation, but to refine methods for permitting the patient to have as much of this invigorating gas as needed. Here, surgeons expect the support of their colleagues—the physiologists, pharmacologists, biochemists—those that are vicariously present in the operating room when the patient's fate is being decided.

The first operation on large vessels in the Soviet Union was performed in 1948 by Lenin Prize Winner Academician Alexander Bakulev. He was followed in the storming of the heart by large teams of scientists under the supervision of outstanding Soviet surgeons like Alexander Vishnevsky, Yevgeni Meshalkin, Boris Petrovsky, and others. In their clinics, thoracic surgery matured becoming a full-blown science. For their work these doctors received the Lenin Prize.

Moscow and Leningrad were the pioneers in this new branch of surgery, and now operations

on the heart and lungs are commonplace in many clinics. Chest surgery is on the march and has already saved thousands of people.

Remarkable changes in recent years have altered the face of surgery. Not only the operating room and the techniques of the surgical maestro, but the very mode of thinking of the surgeon himself. Just yesterday stopping the heart would have filled him with mystical terror, today he calmly applies it in the interests of the patient. And fantastic though this may seem, there is not a jot of the visionary, nor is it for the sake of experimentation. It is an absolute necessity. To operate certain defective hearts has required moving deep into the heart cavity, where the surgeon ordinarily worked in the dark, so to say, under a constant rush of blood.

To stop the heart, switch it out of the cycle of blood circulation and work in the dry was something that even the boldest science-fiction writer did not dare to dream of just a little while ago. A little while ago, but not now, for we already have an apparatus that takes upon itself the titanic labour of the heart and lungs. In the Soviet Union, it was developed by a team of surgeons, engineers, and physiologists of the Institute of Experimental Surgical Apparatus and Instruments.

This apparatus for artificial blood circulation is called a heart-lung machine. The machine is new and occasionally faulty, but what can you

expect from laboratory-built heart and lungs that have to pump blood through vessels, oxygenate it, regulate pressure and do a host of other things for the doctor. All responsible work as you see. And still the surgeon will soon be able to entrust this mechanical wizard with all the duties of the heart. Then the heart muscle itself, switched out of the blood stream, will be nothing more than an empty muscle sac open wide to the eyes and hands of the doctor.

The surgeon no longer has to grope in the dark when operating on the heart. He now has access to complicated and just recently incurable defects. Which means that hundreds and maybe thousands of people will be saved. Thus cardiac arrest, which had always been a sure catastrophe in surgery, has now been placed at the service of life by the determination and knowledge of scientists.

The heart-lung machine is young, yet it has predecessors, a whole family tree. The experiments of Kulyabko and Andreyev were not in vain. Many years later, other investigators continued their work; among them the outstanding figure of Sergei Bryukhonenko. He was one of those scientists who bring flights of fancy down to earth. And though Bryukhonenko's designs are far removed from the latest model of the heart-lung machine, we are endebted to him for the most valuable thing of science—insight into the future.

Back in 1928 he amazed the delegates of the Second Congress of Physiologists in Moscow

with a rather strange breed of dog. At first glance, there didn't seem anything unusual: perky ears, shiny nose and black eyes. It put out its tongue, licked its chops, yawned and crunched its teeth—all very dog-like. But there was one thing lacking. No body! The dog's head lay on a dish and was connected by tubes to an apparatus that constantly pumped in fresh blood. This was a distant predecessor of the heart-lung machine. Together with the cut-off head it formed a whole dog. This was a new breed indeed, and the physiologists applauded the creator vigorously.

Bryukhonenko of course realized that his instrument could not replace the heart. In those days the problem was insuperable. But a quarter of a century later designers took up the job in earnest. That was a different age, a different aim and the difficulties were unlike those today. We shall come back to all this later, but now I want to speak of the future of the heart-lung machine.

The time will come when the doctor will be able to reconstruct a defective heart at will. Where nature has been at fault or grave illnesses have left devastating traces, he will perform operations that will restore the normal physiological architecture of the heart. It will then be more than just a temporary restoration of a run-down organ, rather a complete rehauling.

This is no metaphor, but the tomorrow of our medicine. We are at the start of a new era, the surgical treatment of defects of the heart. And when the faulty heart is brought out for repairs,

the heart-lung machine, born of a marriage of technology and medicine, will take over.

The "Sputnik" of Surgery

Engineering wit and precise mathematical calculations are making inroads into the doings of doctors. Medics have long since given up monopoly rights to studying the human organism. Which is a good thing, for engineers and physicists have scrutinized the operating table of the surgeon, and though they haven't learned all the niceties of his manipulations, they have produced a veritable revolution in surgical techniques. They have constructed instruments that radically change the course of many an operation.

For hundreds of years surgeons have used the needle and the scalpel, handling these simple tools with varying degrees of skill. The success of an operation very often depended entirely on the ability of the operator, and probably no one ever thought that an instrument could seriously affect the outcome of surgical intervention, or even the resolution of complicated problems of surgery. The influx of technically minded people into the domains of medicine and their joint partnership have changed that concept quite fundamentally.

The institute that produced the heart-lung machine made surgeons happy with yet another invaluable invention—a device that sews up vessels with mechanical stitches. It can handle the heart muscle and, if need be, the

nerve stems as well. "The Soviet satellite in surgery" is the way it was put at an international medical congress in the United States.

To grasp the significance of the enthusiasm that gripped surgeons when they saw the surgical stapling device, one must know how complicated and arduous are the many-hour operations of thoracic surgery. These operations are the limit in tension of will power and physical strength.

When the surgeon removes a lobe of a lung stricken with tuberculosis or cancer, he has to sew up by hand an enormous number of arteries, minute arterioles and the branchings of bronchi. And all this delicate work calls for the same consummate mastery throughout: the slightest inaccuracy can spoil the whole job. Mistakes are out of the question, for as a rule, they cannot be rectified.

This device, which in one stroke sutures up the stump end of a severed lung with tantalum staples that are harmless to the organism, is a godsend for the patient and the surgeon. It has not only refined the technique of the surgeon and cut the excruciating hours the patient lies on the operating table with open chest cavity, but also sutures better and more securely than the most skilled surgical craftsman.

A surgeon might inadvertently damage a small artery, a practically invisible nerve fibre—the machine does not. It can handle the most delicate surgery. "Sputnik of surgery" is no understatement!

Intratracheal anesthesia, controlled respiration, the heart-lung machine, surgical stapling devices—all strong and reliable assistants of the human doctor. They have done much to create a new and invigorating climate in the operating room. Even a very sick heart need not lose hope. And the search goes in for ever new friends.

THE DOCTOR AND THE ELECTRON

Precision is a stubborn thing. Ingenious reasoning and logical constructions mean nothing because the established scientific fact is its all-powerful supporter. And with the fact one doesn't argue. The fact is invincible. And very proud, for not everybody can get his hands on him. "Mr. Fact," was how Pavlov put it, and he knew how hard it is to get precise facts in medicine. Yet, there is hardly anyone who needs these facts more than the physician. His slightest mistake is felt by the patient. And doesn't he himself die every time a life is lost? The doctor's error is a tragedy for two people at least. It is not easy here to learn by one's mistakes. But one had to, nevertheless.

Over long years of practice, a physician learned most from his failures. Which was understandable, since no matter how observant he was, curing was done mostly "in the dark". There were always so few exact factors, possibly only the temperature of the patient was open to precise measurement. But unfortunately, temperature is not the sole indication of an ailment. The old practitioner determined the other symptoms with the aid of his eyes and ears — not very suitable apparatus for rapid and confident

diagnostic analysis. But there were no instruments.

The finest ear and the sharpest eye cannot detect half of the signs of a deeply hidden heart ailment, whose mechanism is often very intricate. At times, the source of the illness is beyond the physician's capabilities, no matter how trained his sense organs are. Yet the source, the cause is so very important.

The doctor would remain forever outside the pale not knowing what was what if it weren't for the fact that our organs generate electricity. True, in microscopic quantities, but it is sufficient for us to read their message and tell what is going on of interest inside.

Medicine had to break across one of the boundaries of its realm and appeal to electronics. The response was immediate—in the form of a record of the electric potentials of living tissue. That was the beginning. Now the recording of heart and other waves is one of the most powerful diagnostic aids in ferreting out the causes of diseases.

The heart, muscles and all the other organs of the human body now sign their feelings on long tapes of electrical recording instruments. The brain has also left its autograph.

The little jagged line racing across the tape or a screen has become the visiting card of heart ailments. The disorder is revealed and reported long before it gives signs of its whereabouts. This electronic device is far superior to the human ear and signals about trouble coming from incip-

ient disease: Take care, approaching trouble. And if the trouble is already here, it will furnish the information needed for treatment. The fate of a human being is often dependent on such facts.

However, these waves do not give up all the heart secrets of the patient. There are some defects that do not want to be exposed and there is no way to decode their messages. In fact, they sometimes do not leave any traces at all of what is going on inside. These are the doctor's worst trouble-makers. Especially when there is hope of rectifying the situation surgically, for no surgeon will risk opening the heart until he knows exactly what is waiting for him there. Yet to find out the exact type of defect, he has to penetrate the heart cavity. Again a vicious circle! And again electronics broke it.

Interviewing the Heart

This is how the needed information was extracted. New and unusual methods were tried as doctors made fresh efforts to get closer to the site of the "crime". A radio broadcast from the ailing heart—to be more exact, from the defective chamber. Traceless it may be, but not speechless. Murmur is the chief sign of a defect. It is not the only sign, but it is the most valuable. Like a false note it sticks out of the smooth melody of the heart. That is how the doctor determines the kind of disease, each disorder having a song of its own.

Doctors have always recognized heart trouble by ear. The successes have been considerable. But when surgery is envisioned he cannot rely solely even on his experienced ear. Thoracic surgery demands flawless diagnosis, and one's hearing can't always be perfect.

The sound waves weaken as they push through layers of muscle and lose their original melody. The murmur can of course be amplified but the interference gets louder as well. Distorted murmur is definitely a bad cue to go by. To get the sound in its primordial purity, it must be caught where it originates—in the heart valves and orifices. This suggested the idea of implanting a microphone in the heart.

Easier said than done. Just a little while ago the reaction to such a fantastic idea would have been: "Madness!" Physicists were the ones that brought sanity back to the suggestion. They know that the most improbable of ideas are often the most correct ones.

Without waxing lyrical, physicists have made their contribution to studies of the heart—a microphone that fits neatly into the heart cavity. This device is so small that it ought to be called a micro-microphone. I could hardly discern the receiver—a minute millimetre-thick bead—at the very tip of a long probe.

Its journey to the heart began at the elbow. It moved surely and swiftly along the veins, finally reaching the right auricle. Here it stopped and then cautiously resumed its way under the constant control of X-rays. Another few sec-

onds and the goal was reached. The microphone was switched on.

"Attention! This is radio heart!"

At this instant, I heard, as if from far away, like the rumbling deep inside a steamship, an even hum and then a loud and sharp-cut sigh and a bang, and then again—like giant pistons accompanied by a barely audible and hopeless yearning sigh. No, the heart was not complaining, it was working. And this melody in the silence of the operating room sounded like a hymn to life.

But what is this? The familiar melody, yet something else has cropped up and added its discordant note. The doctors exchange worried glances. It is persistent. Like an echo it follows every beat of the heart. It is the natural and full-blast murmur of a defect. Now at last it could be heard properly.

This was the doctor's first "interview" with the heart. And though it lasted but a few minutes, he learned everything necessary for a complete and exact diagnosis.

Usually, however, the microphone is not enough and a tiny electric manometer is inserted into the heart as well. This device measures the pressure in the right auricle and ventricle, and if the probe is pushed further in it will measure the blood pressure in the pulmonary artery, which cannot be approached in any other way. The signals of the manometer are amplified and recorded on a special instrument called an oscillograph. The physician thus notes changes in

pressure inside the chambers during each contraction of the heart.

The knowledgeable reader may at this point wistfully observe: "It's all right on paper, but what about the patient?" Double cardiac catheterization! I was disturbed myself. Yet there were no complaints in the clinic. Medical scientists had found a short and painless route to the heart. This technique is now undergoing refinements. The Institute of Experimental Surgical Apparatus and Instruments has developed a sensing device that serves as microphone and manometer and even picks up electric potentials inside the heart that fill out the picture of the ailment. There is one more thing—it is extra-sensitive.

Sharp as the ear may be at times, there are sounds that pass it by, and there are many sounds beyond the range of human hearing. But the microphone catches these sounds and transmits them to a special device, the heart's stenotypist, as it were. Here the silent sounds come to life and are recorded with the others to form a complete score of heart murmurs.

Electronics has deprived the heart of its classification as an internal organ. It is now wide open. The slightest heart wave, the most trifling sound, the barest fluctuation in pressure are all taken in by the all-seeing eyes and all-hearing ears of electronic devices. The truth is thrashed out in numerous cross-examinations with these witnesses. And if there is truth, there is no place for deformities. The surgeon will see to that.

In time, the doctor may succeed in obtaining valuable information about blood pressure inside the chambers without even entering the heart cavity. Electronic devices will send in radio or sound signals and their rate of propagation will determine the magnitude of blood pressure in both of the ventricles and auricles. Different media have different rates of signal propagation. The speed is largely dependent on the physical properties of the blood. Changing instantaneously due to pressure of the heart walls, the pressure inside the chambers will affect the density of the blood, which will either retard or accelerate the signal. The sought-for quantity will be found somewhere between the start and finish of this signal. Defective valves and openings of the heart impede the outflow of blood thus altering the intracardiac pressure. There is reason to believe that such studies will help to spot defects.

The conception is simple enough, yet its execution is fraught with difficulties. It will become possible when an electronic transducer is devised capable of reducing a host of diverse physical and biological phenomena to a common denominator.

Electronics holds promise of many interesting discoveries not only for physicians and physiologists. It is elevating the chemistry and physics of the remotest life processes to the level of exact sciences. A relatively recent new tool in the hands of biologists is the electron microscope, which has opened up fresh intracellular "galaxies". Yet this is not enough.

Radio waves are now helping to decipher the hyperfine structure of the living organism—its molecular structure. The electron, which up to now had been reporting on external manifestations of the life processes of organs, has now penetrated deep inside life itself—to the protein molecules of the cell.

Proteins Broadcast

Scientists just recently picked up an interesting news item. The minute particles of living tissue are extremely disciplined. They do not race about at random bumping into each other like molecules in solution. Proteins and nucleic acids behave differently. The disorder and chaos of liquids is foreign to them. Their residence is the cell, where every inhabitant knows its place. The definite positions that the protein molecules always occupy relative to each other make for a steady and crystal-clear life.

Crystal-clear, or crystalline, because a living cell is very much like a crystal. It does not, of course, copy it with geometrical exactitude. Its extremely complex composition does not allow it to compete with the classically perfect structure of minerals, but still its molecules tend to arrange themselves in strict order.

In solution, most of them form liquid crystals, to which scientists attribute the principal property of cells—a constant change of shape and exchange of substances, in short, the ability to live. In this way an unexpected similarity

between heterogeneous life phenomena (cells and crystals) disclosed one of life's secrets.

Biologists with good reason have been persistent and exacting in their studies of the unwieldy protein molecules. The structure of every protein is intimately bound up with its physiological function, with the job it does in the organism. Health and disease are, in the final analysis, two different states of protein molecules, which make up all the cells of the body. The sole difficulty is that the number and diversity of these living building materials are limitless.

Every protein has its own architecture, its distinctive features, which, by the way, it carefully hides. This excessive modesty has stumped scientists in their desire to get a little more closely acquainted. But again the ubiquitous electron came to the aid.

X-rays helped to get a clearer view of the intricate molecule of deoxyribonucleic acid (DNA)—the most important component of the cell nucleus. The examination of numerous roentgenograms established the exact distances between the atoms bound in the molecule and the angles between the chemical bonds, and revealed the dimensions of the atoms themselves.

These coordinates were used by biochemists to construct a scale model of the molecula of the acid. When you have a model you can start discussing its functions. One thing they tried to figure out was how the mechanism of protein reproduction—this template that supplies the cells with first-rate building materials—was constructed.

DNA turned out to be the principal component of the protein template or blueprint. This is a very involved device that requires a special discussion, so let us first go back to electrons.

In reaching the protein, biochemists took the fingerprints, as it were, of this ultimately minute particle of life. Yet that was not all. X-rays are not the only penetrating radiation. Radio waves possess the same property. Perhaps they could take a crack at the cell and decipher a few riddles. Yes, they certainly could.

Electromagnetic oscillations are always on the go, as we know. Here, however, their journey is just a tiny run through the cells of living tissue. Short though it is, a lot of energy is lost in transit, for atoms are extremely sensitive to magnetic oscillations and absorb them avidly.

The living cell is no exception. Radio waves coming through its domain pay an energy toll. Meager but perceptible.

A special instrument sums up the electronic race: who started, who finished, and general losses. And then this information is straightway delivered to an oscillograph, which rapidly traces out an absorption spectrum. This is then deciphered by biophysicists who come up with a picture of the molecular events of a cell.

For biologists, radiospectra have become a sort of call signal of all organs and tissues of the living human body. They show the behaviour of molecules inside a cell in the most esoteric

of physiological processes. An invisible radio probe keeps constant tab on events in the finest of cellular structures during acute and chronic illnesses. In short, the cell is studied both under normal working conditions and during "lunch hour" when it is absorbing electromagnetic waves.

Incidentally, not only radio waves are "eatable" but a whole radio station can be assimilated. Particularly, if it fits into a tiny pill. True, a transistorized transmitter of this kind is not the tastiest of foods, but it is enormously useful.

The patient swallows such a transmitter, which journeys for hours along the gastrointestinal tract continuously sending back its travelogue. These dispatches come from the electronic midget in the pill, which changes the frequency of the broadcasts depending on the surrounding environment.

Special electronic gear respond to these signals, deciphering temperature, pressure of the walls, acidity of the intestinal juices, and other information that interests doctors.

The dispatches of this internal mobile laboratory are trustworthy because they are extremely accurate. The surgeon can put down his scalpel and needle and measure the temperature, say, in the area of the vermiform process (appendix) to within one hundredth of a degree. Other information coming from the inside is just as reliable. Which may mean that that common ailment appendicitis and probably certain other ones as well will soon lose popularity in surgical clinics.

This "stomach broadcasting" is no joke, it's real science. Right now the travelling pill is helping physicians to build up an atlas of oscillations that are typical of a variety of processes occurring in the stomach and intestines. Using a guide like this, the doctor will be able to spot the real cause of an ailment without error or loss of time. He will learn to decode the curves traced out by the receiving apparatus and will be able to peer into the most remote places of the alimentary tract, inaccessible to probes and roentgenoscopy.

Before our very eyes, electronics is pushing traditional methods of examination out of medicine. Only the probe should not worry, it will always be busy. True, with new functions: sounding will soon become a rather formidable competitor of X-rays in stomach examinations.

These two methods had always been good and true friends over the years, and now they are competitors. Real competition. The probe itself now goes on an inspection tour of the stomach, and, unlike X-ray machines, from the inside and not from without. This newly acquired independence is due to its eyes—six stereoscopic lenses each the dimensions of a pinhead and all attached to a match-sized device. This "match" is attached to the end of the probe, introduced into the stomach and for an instant lights up. During the flash, it photographs the mucous membrane. From the negative a print is made and the picture is ready. And an extraordinary photo it is. The walls of the stomach are furrowed with

long tortuous grooves or folds. Three-dimensional images make them look like an aerial photo of a mountain ridge. The importance is obvious. For half a century or more X-rays have been giving us silhouettes of the stomach, while here for the first time doctors obtained a snapshot full face and in colour. Something never dreamed of.

The roving eye of electronics is truly all-seeing. It probably won't come as a surprise if medics start telecasting from the heart, the bronchi or the gallbladder.

This is no science fiction of 2000 A. D. Television cameras less than five centimetres in diameter are already functioning and have found applications in the mining industry. They are used in drilling deep narrow-bore holes. The physician sometimes has to peer deeper down than the geologist. So we can expect some advances with the microminiaturization that is now refining electronic devices. Electronics is going so small that teleprobing of the living organism should in time become a very routine procedure. As it is, television is already active in the service of health.

Surgery in Full View

Why? Because every operation, even the slightest, serves two purposes: the main one, to bring the patient back to normal health, and a subsidiary one—instruction.

Surgeons are trained not so much by lecturing as by showing. Important as lectures,

textbooks, anatomical atlases and sessions in the dissecting room are, the main thing is the operating table and being right alongside an experienced colleague. Here the student watches the endless stream of minute elements and deft movements build up into the true art of the surgical master craftsman. No word descriptions can take the place of actual eye experiences.

"Better to see it once than hear about it a hundred times", is a maxim best understood by surgeons. Therein lies the difficulty, for even an observant trainee finds it hard to follow all the movements of the operating surgeon.

No matter how intently he watches the hands of the maestro, details will escape him, especially the goings-on deep in the wound. And no one is to blame. The small distance separating them from the operation field is something in the nature of a moat between the surgeon and his pupils.

Television has brought the operation out onto the screen.

Over a square metre in size, the TV screen gives a full picture with all details of the maestro performing surgery. And now when a many-hour battle for life starts up on this silverish field, tens and hundreds of intent eyes—not two or three pairs—are watching. What is more, they see everything as clear as day: the needle deftly flashing, the delicate suture on a deep-lying vessel and even the shades of blood from dark brown to bright red.

Here television has added yet another, unexpected, effect. The open cavity in full size and natural colours makes one forget that this is a cold screen and not the living flesh. One does not feel that he is standing in a crowded hall, but right behind the surgeon, and at times one wants to put a question, ask for advice—which, incidentally, is how things are now done. The audience and the operating surgeon communicate by radio.

On the screen is a chest cut wide open—a pulsating blob, on the background the calm voice of the doctor.

Television has thus again demonstrated that surgery is a real art.

What is more, television is a great time saver. Professors and visiting specialists can speak to an audience of thousands. Students from different departments (maybe even different cities) will be able to listen to lectures by the biggest scientists of the country.

No sooner was the television eye recognized by medics, than it was put to the most unusual tasks, at times very responsible ones, like monitoring dangerous cases.

Yes, the television camera will be both a source of recreation and an excellent nurse observing every bed. The patients won't be disturbed in the least, and the duty nurse can peep in a dozen times without ever leaving her chair. A press of the button and the patient flashes onto the

screen. Any complaint or request will be immediately attended to.

One shouldn't get the idea that medical electronics is working only against disease. True, this is its main concern, but it is also playing its part in helping the healthy, even the superhealthy—athletes. Here the screen shows us the race track, the swimming pool and more, and alongside the TV set is a small device dear to the heart of all sports doctors. This apparatus constructed just a short time ago by engineers of the All-Union Research Institute of Medical Instruments and Equipment has extraordinary qualities—it determines the stamina of a sportsman and the limit of his record-breaking capabilities.

The sports doctor has always been in a tight situation studying his patient. He can examine him at the start and finish but he doesn't know much about what is going on during the run, when the body is under peak loads. Yet it is only here that the ultimate potentialities can be determined. That leaves us running after a sprinter with a 15-pound electrocardiograph and other gear.

It was decided to bring the investigations into the doctor's office. The cyclist bears down on his pedals right there without moving an inch, the wheels spinning like mad just off the floor; the long-distance runner pounding along on a moving track, but all the while square in front of the physician. The athlete is doing his workout and special instruments record the work of his

heart, muscles, lungs, and everything else. True, this kind of race in the office is of the convenient and smooth type, rather unlike the tough competition outdoors. What is more, runners and cyclists are not the only ones sport medicine is interested in. How does one go about creating the natural conditions for swimmers or mountain climbers?

And yet a way out was found. That's right, electronics again. But don't think that I'm going to hang a portable electrocardiograph around the neck of the examinee. Electronic chains would hardly do when the time is measured in tenths and hundredths of a second.

Physicians and engineers proposed something much lighter—a two-hundred-gram radio transmitter built into a helmet. Projecting from this strange-looking head-gear, in true Martian style, is an antenna that beams out waves of the heart muscles picked off the body by miniature sensing devices. The receiving equipment may be stationed wherever desired, at the stadium, at the physical-culture institute or in the physiological laboratory. Between the doctor and his patient-by-correspondence lie kilometres and radio waves. The doctor monitors the heart of the athlete while sitting in his office in front of a tele-electrocardiograph. Even this is not all.

The electric potentials of any skeleton muscle are just as amenable to radio-recording and transmitting as the heart muscle. Recorded "on the go", they give a detailed report of the

respiration and all other movements of the sportsman. Sensing devices on the runner or the skier record all the merits of his muscles: rapid and sudden contractions, instantaneous relaxation and many other things that will tell the doctor and the coach a lot more than the highest-speed motion-picture camera.

Now, the mountain climber holding on to a crag, the jumper in flight, the speed skater in a long-distance race or any other athlete for that matter, can be monitored all the time under the actual conditions of his sport.

Sport is not all. The new instrument is already hard at work in the forge shop of the Likhachev Automobile Factory where it keeps tab on the state of operators doing drop forging work. This radio-telemetering technique makes it possible to watch the miner at the coal face, the foundryman pouring steel, the deep-sea diver at the bottom of the ocean, the test pilot in a supersonic jetcraft, and workers of any other profession that requires constant physical exertion.

This device is an excellent consultant for the doctor in out-of-the-way places, inaccessible mountain regions and at Arctic wintering-over stations. A cardiologist who receives this radio information from his distant patient will see at a glance the whole electro-recording of the heart function. He will decipher it and radio back comprehensive advice. If necessary, the doctor will get an X-ray as well. And not by mail—instantaneously. He will examine the patient

at a distance. Image-converter tubes will amplify the brightness and picture contrast of the X-ray, and television apparatus will deliver it to the clinic. This method has the added advantage that the doctor does not receive any irradiation.

In the clinic of the future, the physician will be shielded from X-rays by a thick wall. The patient will be in a closed cabin, the doctor with his television gear will be in a roomy well-lighted office.

No, that was no slip. I mean light. Both darkness and harmful radiation will no longer plague the X-ray man. Image-converter devices are already capable of increasing image brightness a hundredfold, making it more clear-cut and building up contrast. Daylight is no longer an obstacle. That is not all. The shadows flickering on the TV screen can be amplified a thousandfold without any harm to the patient. Which means that diseases like tuberculosis and, possibly, certain forms of cancer, can be detected in the very early stages when it is easiest to fight them.

Thus, day by day electronics is changing our views about the medicine of the future and is making its contribution to this ancient and yet eternally youthful science. And it is not only the medical men who are benefiting from the generosity of modern physics. There is probably hardly a single sphere of the life sciences that has not experienced its invigorating strength. Bioelectronics—bionics—is also helping in space ventures.

Electronic instruments monitored the state of the dogs Belka and Strelka that rocketed into outer space in the autumn of 1960. Television apparatus relayed valuable information from the ship concerning the behaviour of the animals under these unusual conditions. Research workers could sit calmly in Moscow and experiment far out in space. And though the flying laboratory was at times great distances away, the experiment was a complete success. It brought medical men and physiologists to a very important conclusion: living beings stand up very well to weightlessness and to protracted accelerations. This was a rehearsal for still greater events.

On April 12, 1961, the first human being, Yuri Gagarin, was launched into space. And on this historic trip the television camera was busy from start to finish watching the functioning of his heart and lungs. Terrestrial observers probably knew more about Gagarin's health than he himself.

Since then many cosmonauts of the Soviet Union have explored the depths of outer space and every time radio-telemetering systems have played extremely important parts in the general space programmes. Instruments keep careful watch over the spacemen, sending back electrocardiograms, blood-pressure readings, respiration rates at all stages of the flight. And television screens show biologists the spacemen at all times so that comparisons can be made with the objective recordings of instrument readings. Television cameras were again running full time

during the momentous exit of cosmonaut Leonov from his spaceship into outer space recording his extra-vehicular activities. So much for radio-electronics in space explorations. Let us now return to earth. Here again electrons are hard at work performing a multitude of tasks.

Diagnostic Complex

Television has made it possible to clear the operating room of all onlookers, it has become easier to move about with instruments taking over.

Objectively and noiselessly they assess the state of the patient and the tactics of the physician. Surgeons never make light of the electronic opinion. They are very attentive to their helpers, actually never taking their eyes off of them. Every apparatus is attended by a specialist, whose duty it is to keep things functioning smoothly and immediately report the slightest trouble to the surgeon.

In the operating room, the voices are calm and even as they report from time to time on the state of the brain, the depth of anesthesia, oxygenation of the blood, changes in arterial pressure, pulsations of the heart—in a word, about all the vitally important functions of the organism. The dispatches of the instruments are brief and exact, like army orders. This is the atmosphere of the operating theatre. And at the decisive instant when the surgeon cuts into the bloodless heart or the soft rosy-gray mass of the brain,

he is confident that his helpers, human and electronic, are on the job. True, there are quite a few now, but changes are in view.

Designers of medical apparatus have suggested joining all the main instruments into a complex, a sort of "diagnostic combine" controlled by a single operator. Physicians and engineers working in the Leningrad "Biofizpribor" Laboratory have just completed one. It is quite expensive of course. The aim has been to construct a special composite piece of equipment that would take the place of a series of instruments and relieve a good dozen doctors. This device will simultaneously record all variations occurring in the organism on a single paper tape. Just a glance will suffice for the surgeon to get a fully integrated picture of the functions of all the most important organs. He will see not the separate cardiogram or the curve of arterial pressure but the complete commonwealth of the body's physiological systems.

Naturally, this "combine" will not release a ready-made diagnosis, its aim is more modest—to put into the surgeon's hands as many exact facts as needed for a rapid and correct evaluation of the state of the patient. This apparatus will be indispensable at emergency stations that handle cardiovascular disorders, for here precision and seconds are especially esteemed.

When an operation is in progress it is often necessary to obtain a rapid, almost instantaneous, analysis of the intricate lines and pips of the multitude of graphs. It is dangerous to rely on a glance at the record, and there is no time to take

measurements with ruler and compass. The surgeon must make split-second decisions, but how? The answer is computers—electronic computing machines. They too have come into the clinic, occupying an honoured place right next to the electronic diagnostic machines.

The instruments that we discussed earlier took over functions that could not be handled by the imperfect human eye, ear and other sense organs. These new devices can do more. They have a kind of intelligence, it would seem. And they can remember and even think a bit, sort of meditate if they have been "taught" (programmed) to do so.

These machines are being discussed. Some medical men can't seem to get used to the idea of such unorthodox consultants around the clinic. But most doctors have welcomed them and don't regret it. These thinking machines do an extremely important job helping to straighten out the host of scribblings that come out of electrical recording gear. This is not only a complicated and time-consuming job, it is not even always intelligible.

The brain is the most mysterious of all, as always. For quite some time now it has been giving scientists regular headaches. For over half a century brain waves have been recorded and thousands of intricate scribblings need to be deciphered. Specialists are still racking their brains, decoding these signals. The wavy lines are something reminiscent of the hieroglyphics of ancient Egypt, the sole difference being that the brain is "multilingual"—every person has

his own encephalogram. Like the face, it is distinct, no two alike. And mobile too. Always changing due to constant fluctuations of the electric potentials of nervous tissue.

Thoughts, sensations, movements all generate immediate response. I recall how surprised I was once when a doctor standing over the moving tape of the instrument and with his back to the patient, suddenly said: "Stop blinking." He had seen "reflected" light in the graph.

Even during one's sleep a portion of the brain is wide awake, always on the watch, ready to signal a warning. This soundless monologue is one of the greatest mysteries of nature.

There might have been no sense in bringing all this up if it weren't for electronics intervening. During recent years certain laboratories investigating the human brain have been using an ingenious device that is teaching physiologists the alphabet of electro-encephalograms. As is the custom, reading was begun in syllables.

An electronic analyzer carefully "prepares" a brain wave curve. Like a prism breaking down a ray of light into its spectrum, this apparatus decomposes the brain wave into its elemental component parts. At the same time, other instruments compute the mean magnitude of fluctuations every minute and trace out a curve.

This spectral analysis of brain signals repeated many times has done much to decode the secret messages of the central nervous system. Scientists now have a key to these coded dispatches. Imperfect though it is and largely confused,

it has enabled us to peep into the "private" life of the brain. One of the most exciting brains investigated was that of Albert Einstein.

Once the eminent physicist was carrying out some rather involved calculations under the observation of electrophysiologists. At first the work proceeded smoothly. Einstein was counting automatically—that's the way they put it—and the instrument recorded uniform variations of brain waves. Then, all of a sudden, the ridge of rhythmical waves vanished, the scientist looked worried—he had noticed a mistake made the day before. Einstein's upset state and the concentration of attention on the error were immediately reflected on the recording tape. The quiescent waves were blocked by other, stronger, nervous processes. When the error was rectified, Einstein continued his work and rhythmical waves set in again....

The encephalograph demonstrated once again that any difficulty that holds up thought, any problem that requires particular attention straightway alters the electric mosaic of the brain. This of course was still a very halting and rough, yet correct, understanding of the mysterious mechanics of human thinking.

The new device sometimes stumps scientists, and occasionally plays a practical joke. This is what happened once to a serious physiologist. In the midst of an experiment it once compelled him to root for a football team. The real football fan was sitting with electrodes on his head and, while the experimenter adjusted the analyzer,

was listening to a radio broadcast of the game. In a few minutes the physiologist found himself getting interested in the game too. The tape which was recording the brain waves of his patient gave a clear-cut picture of the whole game. As long as the local team held the opponent, the brain showed no interest—just monotonic signals. But when the visiting team began to put on pressure, the brain got excited and worried: frequent waves started to appear. And when a goal was scored by the other side, there was a whole machine-gun burst of electric oscillations of a special shape. Later the game evened out a bit and waves of both kinds mingled. Just watching these waves it was possible to follow the course of the match. And from the electro-encephalogram one could determine the team that the patient was rooting for.

Of course, brain waves are analyzed for more things than sorting out football passions. These sparks of nervous tissue have for scientists become guiding lights in the dark labyrinth of mental ailments. Recorded on magnetic tape, they give food for thought to electronic computers, which go through the brain waves and point out the regularities of mental illnesses.

Brain waves help neurosurgeons to locate tumours without opening up the skull. The institutes of neurosurgery in Moscow, Leningrad, and Kiev have recently been using complex machines that help physicians to make correct diagnosis in 80 cases out of a 100.

Soviet physiologists are investigating brain

waves to resolve the secret of sleep and anesthesia. A device has already been designed that automatically regulates the supply of ether during an operation. It operates on the basis of the electric brain-wave record of the anesthetized patient. This record gives a complete picture of all stages of anesthesia.

The apparatus does the job no worse than an experienced anesthetist, for it does not need to see dilating pupils of the eyes, the corneal reflex and other external signs of narcosis. It gets its information—exact data—straight from the depths of the brain itself. If the brain waves signal "coming out", it adds some gas, if sleep has become too deep, the stop cocks are closed. That is how sensitive the device is.

True, experienced surgeons are now convinced that in such a responsible procedure as ether anesthesia, it is dangerous to rely solely on electro-encephalograms. Automatic anesthesia requires more information about the state of the patient. But this is no problem. Electronic devices can extract any amount of exact information about the patient. Now, in addition to the shorthand record of brain waves we feed into the anesthetic apparatus a constant flow of information on arterial blood pressure and the chemical composition of expired air. Sleep is induced under a triple control of the most important physiological systems: nervous, cardiovascular, and respiratory.

The time will come when doctors will possibly induce sleep without narcotic gases, simply

by putting on a helmet with electrodes that will deliver "narcotic" impulses recorded on magnetic tape.

Very interesting experiments of this nature were recently carried out on dogs. A dog was anesthetized with ether and a taped record was made of the electrical impulses of the brain. This record was then delivered to the brain of a waking dog, which immediately fell into a deep sleep. Then the experiment was reversed: the brain waves picked up from a dog in full wakefulness waked up a sleeping dog.

It is too early to draw any practical conclusions from these experiments, but it is already clear that our ideas concerning the properties of the brain are undergoing radical change. I believe the time will come when surgical clinics will make use of electric anesthesia from donor tape recordings just as frequently and confidently as blood transfusions are now made.

True, the heart here too is ahead of the other organs. Definitely born under a lucky star, the heart. It was the first to extricate itself from the slavish dependence on its own waves. Now it functions and rhythmically contracts even when its conducting system does not pass a nervous impulse to the muscle.

But the cardiac ganglia occasionally abuse their autonomy. They detain a heart wave that is hurrying to its "job" (muscle fibre). Blocked, it dies out. And the heart, like an engine with faulty ignition, at times skips, stopping five,

seven and sometimes ten times a day—on occasion, once and for all.

Times have changed. If the real impulse doesn't get through, the heart muscle will straightway get it from two electrodes implanted in the chest. Engineers at the Institute of Experimental Surgical Apparatus and Instruments constructed a pocket power plant that sends 80 electric discharges every minute. If the heart takes time off to "meditate", the ever-alert device (called a pacemaker) will immediately take up the proper rhythm. This is a real watchman. It is extremely sensitive and is always ready for action.

As long as the heart beats away normally, the pacemaker meekly keeps in step. Suddenly the heart stops, the siren goes. Alerted by the alarm, the nurse comes running with a needle. Meanwhile the pacemaker automatically switches into rhythm making. One second, two seconds, and the heart is again pulsating.

Friends have been coming and coming of late, but not a single one as attentive as this.

A real inseparable friend. And no need to be separated either, because designers have built a portable all-transistorized model weighing in toto only about a hundred grams and powered by tiny batteries. This little device will find an honoured place in the doctor's bag for casualty services and in the everyday life of the heart patient. It stays with him at all times. No need to worry any more.

And what if the heart stops during an operation? The pacemaker will take over in this

emergency as well. A tiny metal rod connected to the device is inserted into the oesophagus whence the impulses are delivered to the faltering heart, ordering it to contract, contract, contract.

What of the future? In time, sooner or later, I see the chemist's shelves with drops and tubes and tablets and also tiny circular disks. The physician will write out his prescription starting out as usual with "R_x" for a potent and reliable heart "medicine" in the form of a magnetic tape with a curative recording. It will not have the ordinary pulsating impulses delivered by a pacemaker, but heart waves, the real controllers of the heart. Then the electro-stimulator (or pacemaker) will have reached the acme of its medical career and become a biostimulator, which is an instrument that gives an exact reproduction of the signals of a living organ.

But, as the chemist would say, it has not yet been possible to isolate them in the pure form. Latent and mixed in with other charges of the cardiac muscle, they leave their imprint in the form of an electrocardiogram.

The tracing on the tape with its ridge of sloping hillocks, sharp-edged peaks and precipices is born of a multitude of interacting currents. The scientist's job is to pinpoint, in this motley crowd, the real pacers of the heart muscle, and then record this characteristic signature on magnetic tape and feed it to the instrument. Then these "frozen" heart waves will always be in read-

iness. Like a tape-recorded song, the apparatus will play off its tune for a troubled heart at any time.

The text will be clean-written with every dot and dash and line addressed directly to the heart, where the precision will be mathematical to the third, fourth and fifth decimal places.

This accuracy, fortunately, we already have. Heart impulses are now fed to computing machines, which soberly and objectively analyze the ardent beating of the heart—and in a way the biggest specialist would envy: in one hour a computer reads off and decodes several hundred electrocardiograms.

Now, added to accuracy, medicine has speed. This was precisely what the surgeon had always been wanting, surrounded as he was with numerous blinking dials, flashing screens, reels of tape and forced to make an instantaneous decision about the state of the patient. Now all the doctor has to do is turn around and ask the advice of a high-skilled machine.

Speed is the invaluable property of the electronic machine. This is obvious to anyone who has stood next to the doctor during the tense moments when the fate of a human being is hanging on the second-hand of his watch. All this does not exhaust the potentialities of electronics, which not only analyzes but reconstructs all possible variations of heart "penmanship", both healthy and ailing. Two Moscow institutes—the Institute of Cardiovascular Surgery and the Institute of Computer Machinebuild-

ing—have produced a machine that synthesizes electrocardiograms. It is called SYNEC.

Here is what the SYNEC machine does. In its electronic innards, experimenters generate currents that meticulously reproduce the angular writing of the living heart. Scientists can now copy on tape any heart ailment that exists. At their request, the machine makes a careful tracing of the new outline on its screen. Comparing these synthetic biopotentials with the genuine ones recorded from the patient, doctors seek to penetrate the uncanny machinery of disturbances in heart rhythm and other grave heart diseases. SYNEC helps them figure out the origin of the most minute lines in the electrocardiogram and study the causes of any change—in a word, crack the code of the trouble.

The instrument has already outdone itself by recording curves that patients have never yielded. The fantastic things the machine was writing were at first very disturbing—the outlines of a nonexistent person. Yet, thought the science minds, this might be a dormant ailment, some new hitherto unknown heart disease. The instrument might be predicting new diseases and presaging their discovery. Which was exactly what happened. The profile of one of these hidden diseases was soon found in the flesh, so to speak. Cardiologists discovered an unknown heart disease that repeated in detail the pattern traced out on tape by the electrocardiogram synthesizer. This was probably the first case in the history of medicine when doctors rejoiced

over a new illness. And it is hard to blame them, for the unusual find promises to make electronic simulation of heart ailments a most exciting field of clinical medicine.

Meanwhile, before machines enter an era of creativity, the experience of humans is being utilized to the full. During recent years, computing devices have been studying medicine assiduously. Computers avidly lap up the hundreds of symptoms of numerous diseases, learn to distinguish between and correlate the results of different clinical tests, and are little by little picking up the logic of medical thinking in the diagnosing of diseases. In a word, they are becoming real helpers.

Without noticing it, we have stepped into the world of cybernetics. In just a short time, cybernetics has become an authority among biologists and simply cannot go unmentioned.

An Electronic Colleague

We have already passed it by, but I must say that I was quite disturbed at the beginning of this chapter when I wrote about the doctor's eyes and ears. I felt the accusing glances of my workmates, their ardent objections and their resentment, perhaps. I had wanted to say then that I have not forgotten the many brilliant teachers and great diagnosticians who worked with a stethoscope and observed with their eyes.

There is no denying it, they existed and they cured, at times miraculously. I mean miraculously

in the full sense of the word because we all look to them as oracles, for we ourselves couldn't grasp their wisdom—a sort of semi-science and semi-art. Like the great artists that they were, these eminent physicians carried away with them that inimitable faculty—the clinical flair. Those were the best of the best, the infallible. Yet, were they infallible?

"I consider myself a fairly good diagnostician, but still I would be satisfied if thirty per cent of my diagnoses were correct." Who said these sad words? Who made this admission, a beginning doctor, an inept trainee, a quack, a failure?

No, they belong to Sergei Botkin, a great maestro in the art of recognizing ailments. How many times did he fail at the bedside of his patient before he uttered the bitter words: "...thirty per cent...." Still, medicine likes an individual approach. I believe this principle can successfully be extended to doctors as well. And if Botkin diagnosed correctly in only three cases out of ten, what could the ordinary doctor hope to achieve? The one with the stethoscope. One indeed must have iron health if he wants to be ill.

Be that as it may, when one gets sick he goes to the doctor. He is demanding, irritable, and the doctor has to help. Every one and at all times. But who can help the doctor? Some cases are real puzzles.

Of course, one can always take a reference book, search the literature, ask a consultant, collect laboratory analyses and conclusions. One can, but it takes too much time. To treat

properly and cure, one must recognize the disease at once.

Everyone knows that, but unfortunately, only a few are capable of doing it. Now isn't it possible to put the talent, intuition, and skill of the best clinicians at the disposal of the rank-and-file doctor, and arm the infantry of medicine with the great art of the highest commanders? A very intriguing idea and, what is most important, quite feasible.

It has been said that science only teaches the clever. Computers are no exception. All the outstanding instances of diagnostics will fit into its electronic memory. And there will be space to spare for future discoveries. Of course, the machine will not become a professor, but it isn't meant to. The electronic "colleague" is not out to get a degree, though its education is definitely higher than high. It is modest and disinterested. What electronics offers us is invaluable—a phenomenal memory and lightning speed of reasoning. Even an experienced physician should not shun it. The thinking machine does not oust the doctor from the bedside of his patient, but rather brings him closer.

Naturally, the old "What is bothering you?" query will no longer suffice. The electronic diagnostician is a mathematician and it needs exact, objective facts about the patient. This information it will receive from the physician and his helpers—the complex of electronic gear that monitors the fundamental processes of the patient. And if the consultant needs additional information

(for instance, about the chemical composition of the blood, roentgenoscopy of the lungs, or the findings of percussion), it is introduced in coded form. So far, this is the only language the machine understands. The doctor has to speak through special interpreters—punched cards. The machine performs an enormous volume of work, selecting and correlating many hundreds of symptoms, and turns up with the diagnosis, which is printed out.

Computers are already defining certain heart ailments without fail. They read off coded heart-wave records and in one or two seconds reach a decision. An expert of this category can sometimes simply glance at the electrocardiogram and name the trouble at once. This instrument is a narrow specialist, for it knows only the cardiovascular system. And although its qualification is highly valued among the medical profession, the diagnostic capabilities of the computer can be developed and refined enormously.

The electronic memory of a computer system will accept any programme that is fed into it. It can be loaded with the symptoms of literally hundreds of different diseases and made to manipulate them properly. An adviser like this will become a highly desirable participant in the most authoritative consultation. And the marvellous thing is that the memory never gets rusty. Thousands of practitioners can, in difficult cases, resort to this silent worker that has imbibed the distilled experience of the world's greatest brains.

Imagine a telegram to the capital coming from a north-pole station, a distant taiga settlement or a mountain-climbing party. All the signs and symptoms of the disease will be coded, and the radioman will hardly finish the last row of dots and dashes when the machine coughs up a probable diagnosis together with the necessary advice. Here in Moscow the computers will certainly be busy.

There will be a Central Medical Repository, a sort of file containing information on the health of several million people. Not long shelves with thick case histories, just tiny punched cards. The attending doctor will each time record new complaints of the patient, the results of additional examinations and tests. The machine will compare them with earlier information, give an analysis and, noting the most important changes between the two visits, will report to the doctor on its findings. With a report like that before him, the physician will find it much easier to see the development of a disease.

No matter what they say, computers do not threaten medicine and will not oust the human doctor, they will expand his logical thinking and, hence, his power over illnesses, making him assess the facts more scrupulously and allowing him more time with the patient.

Gorky was a great lover of life and would never tire of repeating the energetic words of Dickens to the effect that life is given to us

with the injunction to defend it courageously to the last breath. This is indeed so, for man's entire sojourn on earth—from the first cry of the newborn infant to the last heartbeat—is a struggle. A hard fight that is not always victorious. Now a new and strong ally—electronics—has joined in this life-asserting combat of the healing forces of the organism against their foes.

IRON HEALTH

This is not the first time that machines have come to the aid of man. They are tried and trusted comrades. They help in work and there is hardly a facet of one's whole life that is not intimately bound up with machines.

Above all else life is health. It is here that engineering thought is making an ever greater contribution to this most precious of human values. Medicine has already received bounteous gifts that open up fresh vistas for tackling disease and ailments. Industry is constantly supplying new devices and instruments: electron microscopes and anesthetic equipment, ultracentrifuges and electroknives are commonplace in laboratories and clinics. But there is a field in which engineering is just taking its first steps. The temporary replacement of diseased organs by mechanical devices. Even the breathing spell that these machines give to the worn-out body may be a decisive factor. But most often they will be used in radical operations. If a vitally important organ needs rest, the patient will not die, the functions of the organ will be taken over by an artificial, substituting organ. Other devices will be doing

constant duty for lost parts of the body, they will always be on the job in the patient.

Let us get acquainted with these human organs made out of plastics, glass and steel.

The Iron Hand

I had never shaken a hand with such sincere joy and delight as this one. I shook it with all my strength, I pressed it and tried to express my feelings with my hands. And it responded: my palm was caught in an iron grip. This is no exaggeration—the hand was made of iron. It was iron, and it was gentle, clever, obedient, and, what is most important, incomprehensibly keen-witted. It responded to the most intimate of human thoughts and, like a real hand, obeyed.

A person could entrust it with unexpressed ideas, it grasped them without words or hints. If one thought of picking up a glass or shaking hands, the hand immediately prepared itself to fulfil this mental desire. Yet they were separate things. When I exchanged a handshake, I stood near the hand, while its owner was on the other side of the room. Yet all he conjured up was performed straightway. Before my very eyes, thought was translated into action.

This is no dream but the most down-to-earth reality.

One could begin to imagine black magic. Then we perceived a connecting wire, an ordinary piece of wire. It stretched from the iron

hand to its owner and disappeared in a narrow bracelet that fitted on just above the wrist. Just as we were getting things clarified a new mystery arose: How does a person control this strange "hand" contrivance?

I had seen robots with bodies and innards made up of coils, levers and relays, ship models, plane models, operated by radio. But this? There were only the two of us in the room; my companion took up the Napoleon stance and stayed that way. He didn't move a finger, all that functioned was the mechanical hand. The machine guessed his hidden thoughts with unusual sensitiveness. It was obvious that signals were moving over the wire line. But what kind?

The invisible agent was a barely detectable electric discharge that coursed through the nerves at the instant that the brain delivered the order to the muscles. Not a single muscle would move without these waves. They are the ones that scientists harnessed to do the job.

This was a difficult task, for the current that excites muscles to action is extremely small. It had to be amplified by special devices which gave it strength. They amplified but they could not distinguish commands.

Muscles have it easy in that respect, they receive signals from nerve fibres, but an artificial hand has to make sense out of the stream of impulse orders before it can act. The hand had to develop its own brain and nerves. An electronic machine distributes the waves (biological

currents) and sends them to their destination. The rest is simple.

An impulse of a live muscle passes through amplifiers and an electronic brain and operates electromagnets, which control a flow of liquid oil inside the iron hand. The oil pressure moves a piston in one direction, then in the other. Through a system of levers it opens and closes the hand. The fingers do not merely press, they very precisely duplicate the muscle movements mentally dictated by the human being. The hand obeys his every whim or wish, it becomes strong, energetic, or limp and unresponsive. The metallic model is, to a degree, already capable of expressing sentiments, but the time is not far off when it will be able to feel.

The engineers and doctors at the Central Prosthetics Institute have refined this marvellous invention. Their aim has been to make the artificial hand light-weight, mobile, capable in most cases of replacing the real hand. Just recently they hooked up a small, long-term battery. Now the invalid can use the gift-hand almost like the one he lost many years ago in the war. Yet this is not the end.

Scientists are thinking of a feeling hand capable of distinguishing heat and cold and hardness and projections. The owner of a limb like that may go so far as to complain that his hands itch. There is still more. The upper limb must move in the shoulder and elbow joints.

To fashion a piece of metal so that it does the work of an organ that was refined over millen-

nia! Really, golden hands are making iron hands.

But, as they say, you can't take everything into one hand. Machines controlled by thought may perform many other no less important services. It sometimes happens that a person is helpless even with all his arms and legs. His limbs hang limp because poliomyelitis has destroyed most of the cells of the spinal chord and the remaining intact cells generate only negligibly small biocurrents. The muscles are healthy, but there is nobody to guide them. And they perish through lack of exercise.

Here this apparatus comes to the aid and picks up the electric signals of the normal nerve cells making the muscles perform. The patient will move and exercise his feeble limbs until work revives the muscles and excitation—a most important property—is restored to a certain part of the nervous tissue.

If the disease afflicts portions of the spinal chord that control the respiratory muscles, "iron lungs" built on the same principle will take over. Currents of the intercostal muscles will automatically regulate the frequency and degree of rarefaction in a metal cylinder holding the chest.

When the pressure inside the hermetically sealed iron case is below atmospheric pressure, it will suck out the ribs and the chest will expand—the lungs will take in air. Three or four seconds later, as it collapses, they will push it outwards. A sick person almost devoid of

nerve cells that control respiration will himself set the pace and depth of breathing as before.

And what about the heart? Its muscle also has a continuously varying electric potential. Ordinarily, doctors record heart waves to help in diagnosis. Everyone is familiar with the jagged tracings of electrocardiograms with their coded heart waves. Isn't there some way of extracting some good out of them?

Yes, there is. And quite a bit too. Heart waves have been made to operate an X-ray apparatus, which they trigger to make lightning-fast—in a hundredth and a thousandth of a second—snapshots of instantaneous phases of heart activity. The heart records itself and enables the physiologist and physician to take a more careful look into all stages of heart performance. These fleeting pictures leave traces that medical workers use to track down the actual cause of the ailment and elucidate all the niceties of heart mechanics.

In the future, such waves will operate not only X-ray equipment, but also many other devices and machines. At danger spots or inaccessible places, man will send in mechanical hands. They will be remote-controlled by radio, and a television screen will help to follow the execution of the programme.

Sitting in an armchair, one will operate atomic reactors and high-voltage transmission lines, work on the bottom of the ocean and in deep space. Iron hands will function inside blast furnaces and deep down in the earth.

Robots of this kind will have a lot to do here on earth and in outer space as well. They may be the first explorers of other worlds. Delivered to other planets by spaceships, they will carry out intricate assignments under the guidance of terrestrial operators. They will collect samples of ores, dig and drill holes, construct landing strips for big interplanetary vehicles and....

It is already obvious that the discovery of Soviet scientists is only the beginning of a big and exciting branch of science. How dear to heart the easy start.

Farsighted Skin

A short word "eye", yet how important. The limitless expanses it encompasses are especially felt by those who lose it. No less than four fifths of all the impressions we receive from the outside world come through this tiny window. There is wisdom in the saying that one's eye is better than a brother. And closer than a brother would be the person who could cut a tiny slit for the blind to get back a minute portion of vision. All this savours of fairy-tales. When an eye is lost, it is gone for all time and there is nothing to take its place.

There would hardly be any sense in repeating this sad truth if engineering genius hadn't done something to rectify an otherwise hopeless situation.

The Soviet physicist Professor Nikolai Valus set out to encroach on the monopoly of the eye.

His starting query was: "Is it not possible to see by means of the other sense organs?" Without restoring the eye, it might be possible to make the blind see again. His aim was to transfer the duties of the eye to the skin, for the skin sends a variety of sensations to the brain. After a certain amount of training, the brain learns to convert these signals into images, pictures, letters.

For years, the blind have been reading with the fingers by touch. Now the old technique has got to teach them to see. The sense of touch, or tactile sense, was instructed by the scientist to convey light signals to the brain cortex.

But the eye sees at a distance while the skin feels only by contact. To expand the world of the blind, the skin had to be made farsighted. Here was where the physicist came in.

The reasoning was simple. The eye is, above all, an optic instrument, the living prototype of the camera. It is where rays of light are converted into a visual image. Nature itself suggests the solution of the first part of the problem—the catching of the image. A dark chamber the size of a matchbox and a lens with an automatic diaphragm became the first section of the path that a light signal traverses towards the brain.

The next step was more difficult. The retina of the eye converts the ray into a nerve impulse that races to the brain. How replace it?

Photocells helped to convert light signals into electric signals. The scientist arranged them in the focus of the lens like honeycombs. Light

rays fall on this light-sensitive mosaic, eject electrons and generate currents. The brighter the light, the stronger the current. The electrons build up like an avalanche. Knocked out of their sites, they race towards the positive pole of the tube and on colliding with a metallic plug, give up their charge. This charge is a coded particle of the image, one of a multitude that go to form the visual image in the large.

But the brain is not adapted to the reception of electric signs directly from the photocell, while the optic nerve withers away in just a few days after the loss of the eye. The ray of light has come to a halt just short of the cherished goal. Another route must be sought to relay it to its destination. The idea then arose of routing it along the sensitive nerve fibres of the skin. This would be the most difficult section of the light-signal relay race to the brain.

Thus the last link in this chain was a tiny ball, which plays the part of messenger between the charged plug of the photocell and the skin of the forehead. There is one ball for every tube adjoining the photocell. The metallic plug attracts the ball, gives up the accumulated electric charge and then repulses it. The larger the charge, that is, the brighter the light ray that initiated the flow of electrons, the faster it jumps back. From the force and frequency of the impacts of a host of oscillating balls (there are several hundreds of them), a blind person can form images of surrounding objects with the clarity of a self-made television set.

This does not occur from the very start, but only after the tactile centre of the brain is retrained for visual work and begins to respond to vague outlines of objects, to pictures and finally to a spatial distribution of things. Then a blind person will be able to walk freely along the crowded streets of a city in the twilight without running into things. This is because fog and darkness do not hamper the electronic eye, which is capable of recording and amplifying the slightest beam of light.

Now what about energy? A photocell requires high voltage. Maybe haul about a storage battery or generator? Hardly. This is no small snag, it may blow up the whole idea. No! Recent advances in electronics, particularly in semiconductors, have overcome it rather easily. One has an excellent power supply for photoelectric devices. Pocket batteries will do the job at night, while semiconductor solar batteries can take over in the sunlight. Solar batteries generate electricity by utilizing the sun's rays and can store it up for nighttime use. Convenient, cheap and very practical. This electric eye will be a boon to the blind.

The mosaic of photocells and light-sensitive skin will take the place of the blindman's retina. Using them, he will be able to read. The explanation is simple: the little spheres will oscillate only in those tubes on which light reflected from letters impinges. The letters will be projected with precision on the forehead. Each letter reproduces its image on the mosaic of photocells. And

the messenger "beads" tap it out lightly on the forehead. The blind person perceives this alphabet and builds up the words by syllable, then whole phrases will bring him back into the world of the written word.

Even more can be said. Armed with an instrument like this one, he will have better sight than the seeing, for the human eye is very imperfect. The great naturalist Helmholtz discovered so many defects in the eye that he exclaimed in anguish: "If the human eye were delivered to me from the workshop, I would return it to be refashioned." This joke was prophetic. Today, the "eye to order" is an actual invention, one of a host of technical novelties.

The electronic eye will have a multitude of interesting and exciting things to do. It might even take a look at the invisible and listen in to the unhearable....

Infrared and ultraviolet rays lie beyond the threshold of our vision. But an artificial eye can have a photocell that will respond to and amplify light waves from different parts of the spectrum. Then the blindman can go out at night too. He will clearly see the invisible. And he will be able to keep his eye any place he likes, even on the back of his head.

In the future, the eye will be revolved by a special mechanism controlled by impulses from the neck muscles, like the iron hand. The head of the blind person will remain stationary, and the artificial eye will seek the light source, for it can easily be made to revolve and hear.

Yes, hearing and not only seeing. The mosaic may be made sensitive to sound vibrations of the very highest frequency. Then the instrument will acquire a new designation—research. It will relay mute sounds to the brain. It may happen that we shall acquire a new sense organ. Like bats, we may be responding to ultrasonic waves and listening in to "fish conversation". A new facet of life and sensation will open up. One little eye, yet how much it does.

The eye may see great distances, but the mind goes farther. Perspicacious, it is about to bring sight to the blind.

Naturally, "farseeing" skin is not the only solution to the problem of an artificial organ of vision. In other cases, inventors have sought more modest goals: an instrument for reading for the blind. We already have some models of these devices.

In one of them, a photocell moves over the lines like an eye, from left to right. It converts the light signals of the letters into mechanical motion—the rising of tiny nails over a flat area. The tip of the finger lies on this polished area and responds to the contact of the nails, which transmit the projection of the letter. Each letter has its configuration of points (nails). This is a sort of hand reading.

Another substitute for the eye is the ear. Again the same photocells can translate words into the language of notes. Each letter, or more

precisely, each line in a letter has its sound convention. When he gets used to these signals, the blind person will be able to read a book just as fast as an experienced conductor runs his eye over the score of an opera.

Some inventors suggest such bold experiments as the transmission of light pulses from a photocell to the brain over wires and the expanding of the image on the optic field of the cerebral cortex as if it were a television screen.

This type of experiment abounds in difficulties. It is not so hard to drill through the skull, and we can also collect a bundle of 700,000 fine wires (the number of fibres of the optic nerve) so that this cable is no thicker than the nerve cable. But what we cannot do is transmit a light pulse from each wire to a nerve cell of the brain. There seems to be some very intricate relationship between the fibres of the optic nerve and the cells of the cortex. When this mechanism has been figured out, we may be close to modelling such a television set in the brain.

In a word, no end of conjectures, assumptions, suggestions and ideas. Not all of them are realistic but what is important is that the problem of artificial eyes has come into the field of view of inventors and scientists. We hope that it will be resolved—and soon.

One Kidney in Reserve

If the Trojans had studied anatomy, they would have known that besides Achilles' heel

there are other vulnerable spots—unpaired organs. They cannot be replaced, and when they go out of commission, it means permanent invalidism or death. Nature did not duplicate the heart, the liver or the pancreas. Though generally inclined to symmetry, it has deviated. Now kidneys were a stroke of luck. Two of them.

Two marvellously delicate bean-like structures that are constantly purging the blood of water and poisonous body wastes. Without these sanitary units a person would very soon be poisoned by his own waste products. Fortunately, disease ordinarily strikes only one of them, leaving the sound one to carry on and do the work of two. But sometimes both are afflicted. Then a catastrophe is inevitable.

For years doctors have dreamed of an apparatus that would relieve the exhausted organ for at least a few hours. And engineers have long been mulling over a machine that could filter blood. The operating principle of a kidney seemed simple enough, but it defied reproduction. Of course, there were no attempts to copy the organ as it was, make a replica of it. That would hardly have succeeded.

The tiny kidney contains seemingly endless loops of urinary tubules enmeshed in a delicate network of capillaries. It is here, in the flood plain of numberless vessels that the blood leaves behind excess water and noxious substances. This is an elegant, balanced and very economical structure. Scientists were immediately aware that there could be no hope of imitating nature,

so a radically new approach was made to constructing a machine for purifying the blood.

There was no need to study the intricate maze of vessels and loops, for it defied duplication. But filter paper suggested a simpler and more accessible solution of the problem. Indeed, does the blood really have to be washed in these endless tortuous pathways?

A new channel was made, broad and flat. It was an extremely fine film of cellophane stretched taut in two layers over a plexiglass frame. Placed one above the other, these sections form a towering transparent fourteen-storey house in miniature. The blood slowly flows down the cellophane stairways and rids itself of waste.

The problem is to get the harmful poisons out, because the blood does not give them up readily. On the other side of the film is a glass vessel into which is constantly pumped a weak solution of nearly the same compounds, with the exception of urea. This is to clean out the noxious substances. At first glance it seems strange, though the idea is simple: from a concentrated solution they pass into a diluted solution. Which is exactly what happens: the solution bathes the semipermeable membrane and pulls all the waste outside, then picks it up and carries it away.

Every little drop of blood that comes in contact with the cellophane deposits its dangerous load and, revived, goes back into the body. The solution, enriched with poisons, drains into a tank. From time to time a little lamp at the bottom flashes on. This is a warning: blood that

has made its way through the film will be immediately detected by the reddish hue of outflowing liquid.

The mechanical kidney is a life-saver in the most unusual cases. Suppose in a blood transfusion, the wrong group of blood was used and the blood corpuscles stick together in little clumps blocking up the kidney capillaries. Inevitable death! But if an artificial kidney is hooked up to the vessels, it will function like the real kidney until all the blood clumps are extracted. A real life-saver.

Even the bite of a rattle-snake is not fatal. A Mexican peasant attacked by a cobra lived five weeks with this metal sanitary device. The organism was purged of snake poison and, what was just as important, the Mexican's own kidneys got back to normal. Without this machine he would have died in just a few days even after the best of treatment.

Connected to any other vessel—on the arm, leg or elsewhere—the artificial kidney can perform a host of other functions. For instance, it can remove extra water that has accumulated during certain illnesses in the tissues and serous cavities. And at the same time, it can introduce drugs, glucose and even oxygen directly into the blood. There is nothing unusual. An artificial kidney connected into the bloodstream can function as a lung for some time, oxygenating and even cooling the blood. Before heart surgery is commenced, the "kidney" brings down the body temperature, creating artificial hypothermia.

Engineers and medical workers at the Institute of Experimental Surgical Apparatus and Instruments have built a marvellous machine that has found wide applications in clinics all over the country. These kidney centres set up in the Soviet Union will doubtlessly save many more human lives.

The Formula of the Heart

And, finally, the heart. What hasn't it been compared to: a motor, a pump ... yet it is incomparable. Which was immediately evident when attempts were made to replace it temporarily. Some very powerful and refined blood-pumping devices were designed, but they just couldn't compete. This three-hundred-gram bundle of nerves and muscle was irreplaceable. It could never take time out—even for the shortest rest—and once ailing, it had to be treated on the go.

This stumped engineers for the longest time. What could be simpler it would seem: switch into the bloodstream an iron pump in place of the muscle one, and there's the solution. Isn't the physics of all hydraulic devices the same? And the blood—though a peculiar juice—is definitely a fluid.

All very true, but the heart has its own laws. The obvious thing to be done was to find these regularities, derive them like Newton did the binomial theorem or Pythagoras his famous theorem. Scientists were confronted with an involved equation that had more unknowns

than knowns. This may have been the first time in the history of medicine that doctors appealed to mathematicians. Greater precision was obviously needed. Such a simple technical problem at first glance, yet it required the combined efforts and knowledge of such far-flung specialists as physicists and surgeons, engineers and biochemists, physiologists and mathematicians.

And all they had in common was the goal and one language. Succinct, exact, expressive. The language of numbers and formulas. Never before did number play so important a role in practical medicine. It was authentic and was worth a whole library of ingenious guess work, conjectures. What had to be built was an apparatus that could pump blood and reproduce the delicate and complex work of the human cardiovascular system, about which the designers of this new machine hardly knew anything.

Indeed, how much valuable information could they extract from the familiar fact that the blood pressure in the arteries depends on the force of heart contractions, the elasticity of blood vessels and other such "elastic" descriptions?

To build a machine, the engineer needs exact calculations. The heart-lung machine that surgeon Mikhail Ananyev and physicist Yevgeni Vainrib and their colleagues wanted to design was no exception. It involved a quantitative expression of the functioning of the heart and vessels. There must be laws governing these things. But what were they?

No one knew. In the Institute of Experimental

Surgical Apparatus and Instruments guessing was discarded. It was fully realized that not hypotheses but precise facts were needed. Real information. The search was on.

Experienced experimenters first constructed a model. And so a model was built reproducing the basic physiological peculiarities of the bloodstream. The aim was to figure out blood circulation, determine the relationship between arterial pressure and elasticity of the vessels, the pulse rate, the stroke volume of the heart—in a word, a great diversity of indicators of cardiovascular activity. This kaleidoscope of phenomena had to be integrated into a single formula—the formula of the heart.

When the model was carefully studied, it was decided to construct.... No, not an apparatus, only an equation, which was worth a lot of machines, for behind the signs and symbols were laws that governed the flow of blood. They were to tell more about the flow of blood through arteries and veins than all the experiments of physiologists since Harvey. This was a very important part of the work. Scientists not only solved the equation, they decided the fate of their apparatus.

The solution was investigated with extreme care, analyzed, and the artificial heart ceased to be an engineering conundrum. A mathematical analysis laid bare the law that governs the work of heart and vessels.

Now the designers could take over. So it appeared, but it was really still too early. The re-

searchers had to go over their figures once again. The new formula would become law only when the slightest doubts had vanished.

Was the conception correct, could the reasoning be faulty, and how rigorously was the formula derived? All doubts had to be dispelled, for it would lie at the "heart" of the future heart-lung machine to which surgeons would entrust the life of their patient during operations. Definitely not worth the risk.

It might be a better idea to use this formula first to construct a curve and not a machine. Which they did: first they did the calculations and then they traced out the curve. A real triumph of science. This curve, which was generated by mathematical manipulations duplicated, to the minutest zigzag, the entire record of arterial pressure of the patient. Thus we came full circle. The living heart confirmed the fact that it functions in strict accord with the discovered law. Which meant that the calculations were correct. The harmony of the human body verified by algebra disclosed one more secret of life.

At this point, engineers could take over and translate the formulas into glass and metal hardware. This they did with ingenuity and talent.

However, science had not exhausted its part with the designing of a heart-lung machine. Scientists determined what materials had to be used in its construction. For instance, it developed that rubber tubing could not be used for artificial vessels of the apparatus because pulsations caused it to change volume, thus distorting the

regime of blood delivery. Elastic and pliable vinyl chloride took the place of rubber.

This problem was hardly beaten when a new difficulty arose: How is the machine operated? Neither scientists nor the engineers knew whether one could judge blood pressure on the basis of signals coming from plastic tubes.

Reverting again to the formula, it was found that correct information comes only from the vessels of the organism. The iron heart was made to obey these vessels. Later, when we succeed in deciphering the wave record of the brain—the first victim of oxygen starvation—its signals will be the cue for the doctor running the heart-lung machine.

It may be that the time will come when electric charges from the brain will take over complete control of the heart-lung machine. Of course, more information will be needed. The machine will want to know about the gaseous composition of the blood, the arterial pressure.... Such information will be flowing in from special instruments. Even the heart will be tapped for data. It will "pump" information into the heart-lung machine on the state of the organism. Doctors are right now designing automatic-controlled artificial-heart machines. An apparatus of this kind would instantaneously analyze incoming information, self-correct its programme of action and monitor further developments.

Here, the artificial heart would become an integral part of the complex life of the body, and with feedbacks the operation would become better

and faster. There is still a lot of work ahead for designers if they want the existing heart-lung machine to replace the heart in a bigger way. Scientists have given much valuable advice and numerous suggestions for designers to digest and put to the service of saving human life.

Here it is, the steel heart and the shiny glass cylinder that does the work of the lungs. Straight from the veins, the blood flows into a counter current of oxygen, bubbling up and avidly devouring its share, and then drips down to the bottom. Pumps promptly return it to the body, sending it into the aorta and along the arteries to all organs and tissues.

And the heart?

It has been switched off. The surgeon is busy rectifying a defect of nature or the traces of a grave disease. Bloodless and motionless, it has finally become amenable to restorative surgery in the full sense of the word.

Surgical treatment of defects of the heart is the principal profession of the heart-lung machine. But it will also help in other no less important cases.

Medical workers have long been aiming at surgery for myocardial infarction. This grave ailment is caused by occlusion of the heart vessel and can be remedied rapidly if a new route is made for the blood along an adjacent artery or if a little bridge in the form of a nylon tube is made from sound vessels to the afflicted portion of the heart.

But the most important thing is to prevent, not treat. And this is possible. The point is that for the muscle of a sick heart to remain sound, all it needs is something like about fifteen drops of blood per minute. It would be a crime not to borrow this little bit from a neighbouring blood vessel, or, say, from another organ associated with the heart by hidden underdeveloped arteries. The important thing is to connect them in time. Then the blood will rush, by a circuitous pathway, to the starved preinfarction muscle. The heart will receive many more than the fifteen fateful drops and will be rescued.

These operations have already saved the lives of thousands of doomed patients. Here the heart-lung machine has a very special role to play. While the implanted bridges get securely in place, the heart-lung machine will take over most of the work of the overloaded heart. Here is where the formula of the heart comes in. A machine built on the living model will duplicate the functional pattern accurately and smoothly—not for minutes or hours but, possibly, for days on end it will be a component part of the organism, just as natural as any other organ.

Every operating room will have its heart-lung machine in full readiness to bring the dead back to life minutes after cardiac arrest (stoppage of the heart). It will lighten the work of surgeons, making them more confident and sure of themselves and the outcome. From now on, machines will bring patients pronounced dead back to life.

FIGHTING OBSTREPEROUS TISSUE

Diseases, like human beings, have their fate. Sometimes it is the history of a terrible scourge that decimates the land and falls back only before the courage and perspicacity of one individual, then again it is a destructive avalanche of some pestilence which is brought to halt only after enormous lose of life and by the combined and heroic efforts of several generations of scientists. To this very day some diseases are displaying extraordinary stamina and resourcefulness. Medicine carries on a bloody battle paying dearly for every step towards ultimate victory. The science of conquering disease is more difficult than the ability to win the biggest battle.

Then again, from time to time the medical community has inadvertently stumbled over remarkable discoveries that have rid the world of many calamities. Over a hundred and fifty years ago an observant English physician, Edward Jenner, found an excellent vaccine against smallpox, although in the eighteenth century no one could ever imagine the existence of the minute pathogenic organisms of this disease—viruses. The discovery was made completely in the dark, so to speak. But the blow was right in the bull's eye.

This unparalleled find was no accident, of course: Jenner was a real researcher. And still it was a stroke of luck—nature rarely becomes so outspoken even when conversing with a perspicacious naturalist. Some illnesses have been studied much better than smallpox, which Jenner's contemporaries referred to as the pestilence, yet have not succumbed to the most refined remedies.

Among the toughest of human ailments is man's worst enemy—cancer, whose strong claws sink into the body, virtually tearing to pieces healthy organs and tissues. The relentless rampant multiplication of cancer cells exerts its effect first on the neighbouring tissues that surround the malignant tumour. It breaks through the front, as it were, and like an experienced strategist plunges deep into the body, penetrating into vessels and dropping "paratroopers" along the bloodstream that are carried to distant corners of the body. An insidious, dangerous enemy! How can it be repulsed, what weapon can be used to restrain this mad tissue?

The First Find

The beginning was eighty years ago in a small two-storey house in Vyborgskaya Storona, a quiet suburb of St. Petersburg. The veterinary doctor Mstislav Novinsky here was engaged in an unusual job. While his classmates at the Medico-Surgical Academy were writing dissertations on the treatment of glanders and cattle plague, he

was trying to inoculate a healthy dog with a malignant tumour.

The young investigator knew very well that such attempts had been made repeatedly and unsuccessfully, and he too failed at first. Yet after many failures he attained his aim: a piece of cancerous tissue taken from the nose of a sick mongrel dog was implanted under the skin of a healthy dog and took. After a time cancer developed.

Novinsky repeated the experiment a number of times with the same result: the lively romping puppies developed malignant tumours. Then the scientist grew bolder and decided to continue the series and at the same time verify his earlier experiments. "If the pups did actually succumb to cancer," he argued, "then they themselves should serve as a source for fresh inoculations." And he was soon able to transmit the tumour from sick to sound puppies. Under the microscope it proved very much like the piece of tissue taken from the nose of the mongrel. There could be no doubt any longer, the neoplasms (new growths) that developed in the puppies represented real cancer.

This was the first experimentally developed biological model of a malignant tumour. The modest veterinary doctor least of all suspected the broad vistas which his small dissertation opened up to medicine. But what he did know was that the first definite step towards eliminating this terrible disease would be through learning to generate it artificially.

Novinsky's experiment served as a starting point for numerous experiments in the transplantation of tumours between animals of the same species. Research workers learned to inoculate cancer and also to reinoculate it repeatedly from one generation to the next. Year-old puppies were replaced by fertile mice. The malignant tumour was transplanted from generation to generation. One such litter of cancer mice started in 1905 is still living. This is something in the nature of a relay of cancerous cells, probably the first case in the history of science when man overcame the time element and practically achieved immortality of living tissue, even if in a laboratory experiment.

Transplanting tumours helped scientists to figure out peculiarities of growth and suggested to them ways of taming the obstreperous cells. For surgeons it was important to learn from these experiments that cancer grows due to the inordinate multiplication of its own cells, out of itself, so to say. By removing it as early as possible, before it has time to migrate to other organs, they could be confident that the disease would not reappear.

However, even though scientists could transplant afflicted tissue they could not answer the most important and alarming question: Where does the original tumour come from, the one that developed spontaneously and served as the source for transplantation?

A simple question, yet so very involved. To find the answer, one had to get to the original

cause of the sudden transformation of healthy cells into cancer cells, the trouble-maker of this devastating uprising of living tissue. Only then would we get an insight into the true nature of the mysterious tumours. For the past half a century this has been one of the most difficult and exciting of all medical problems, and has given rise to a whole series of ingenious experiments and surmises.

A lot of water has flown under the bridges of the Neva close by the Medico-Surgical Academy during the thirty years that separate the first successes of Novinsky and the experimentation started by Nikolai Petrov. By chance they both were graduates of the Academy, but the young surgeon Petrov had it better. Soon after graduating, he went to Paris to study under that great maestro of biological experimentation Ilya Mechnikov.

There, in the Pasteur Institute, where everything was redolent of its remarkable founder, he realized that the very biggest scientific discoveries are often rooted in the diversified and at times contradictory niceties of laboratory experiments. The experimenter awoke in him when he returned to Russia, to the operating table and the knife (unfortunately only the knife) to cut out the pernicious claws of the crab—cancer.

Petrov went to the laboratory to seek the answer that his surgical scalpel did not yield.

First of all, he decided to check to find out whether it was true (as certain scientists thought) that cancer is due to unutilized germ cells dormant

in the organism from the very earliest days of intrauterine life. His experiment was simplicity itself: he ground up the embryos of guinea pigs and injected them into the kidneys of adult guinea pigs. He did this simple procedure many times before he was convinced that in this way he would not be able to get a real tumour.

Petrov was not grieved by his failure, quite the contrary. If the experiment had been a success and the germ cells had developed into cancer then one would have to think seriously about human beings born with innate rudiments of malignant tumour. A rather bleak outlook for a person to know that he was born with lethal seeds capable of germinating on a sudden and for quite unfathomable reasons. The experiments of Petrov and other researchers refuted this macabre prospect.

Strange Geography

When there arose a suspicion that the leaders of this malignant regeneration of tissue were hiding out not in the organism itself but outside it, scientists set to work eagerly to hunt down these mysterious enemies of man. Here be recalled the chimney-sweep.

This was a sad history of simple little English kids who had to work from an early age cleaning the soot out of chimneys.

A grown-up person wouldn't be able to get down the chimney, but a seven-year-old boy could climb up and down with ease, which he did

carrying away on his clothes and skin soot and coal tar. By the time he reached twenty-five, this boy had cancer of the skin. The disease became known as chimney-sweeps' cancer.

Finally, sometime last century, the House of Commons passed a bill prohibiting the employment of children in chimney sweeping. "Better late than never," was probably what many of the chimney-sweeps of England said ... but then they succumbed to the disease at thirty-five years of age. It looked as if the parliamentarians, like real experimenters, had decided to verify their findings under modified conditions of a mass-scale experiment. But there was no need, for English physicians had long before established the fact that cancer is caused by the distillation products of coal which settle inside chimneys.

In time, measures were finally taken, and chimney-sweeps' cancer disappeared, but many years later scientists looking for the cause of tumours recalled this sad piece of history and reproduced it on animals. For a whole year, the patient Japanese researchers Yamagiwa and Ichikawa rubbed the skin of mice twice a week with tar and finally produced cancer. This was the first successful experiment in the artificial generation of malignant tumours in healthy animals.

To many it seemed that the long search was over and the murderer caught and that he would be brought before the court of medicine for a trial. But cancer did not give in. Experienced criminal that he was, he slipped through the contradictory evidence and escaped.

The point was that not all experimenters were able to grow malignant neoplasms on the skin of mice. For some it went along smoothly, but for others no cancer developed even when hundreds of these rodents were smeared every single day. There could be no talk of advancing before this dilemma was cleared up.

At this point, the chimney-sweepers were brought in again. The chimney-sweepers' cancer was peculiar in one respect: it afflicted mainly the English and slightly less often the Dutch who used coal imported from England. The French and Germans had only heard of the disease, while in Russia it had never occurred. An occupational disease with a very strange geography indeed.

The first idea was to make a study of the chemical composition of different coal tars. They were not the same. Then a comparison was made to see how actively the different tars caused mouse tumours. Gas black took first place as a carcinogenic agent, and was followed by coal tar and blast-furnace tar. It was evident that there are specific substances in nature capable of causing cancer in humans. These substances had to be found if anything was to be done.

Step by step the circle tightened around the elusive enemy. And finally the day came when it was found. The hydrocarbon benzpyrene and certain other aromatic compounds extracted from tar in pure form invariably caused cancerous growths in mice. Tar was thus relieved of suspicions of carcinogenic properties, and the first timid attempts to cause cancer with it ended

in the discovery of its real causal agents—the higher hydrocarbons, azo dyes and certain other chemical substances.

We could conclude our story about the many-year search of the disease-makers if it were a question of them alone. But therein lies the strength of science that it does not recognize final solutions or exhaustive discoveries: each new find is only a step along the way.

Having detected the chemical agents of cancer, experimenters asked themselves another question: In what way do the disease-causing hydrocarbons get into the organism and disrupt the normal life of the cells? Without this knowledge there could be no talk of victory, or of even mounting a reasonable attack on the enemy. That was why a young Leningrad scientist, Lev Shabad, and other research workers in the 1920's took up this problem with such ardour and impatience.

Wandering Carcinogens

Newly discovered carcinogenic substances which had already been studied were Shabad's chief weapon in the fight against cancer. They were known to possess some interesting properties. The first thing to come to light was that one and the same chemical compound causes not only skin cancer but also sarcoma, a malignant tumour of connective tissue. To produce a sarcoma, the chemical had to be injected under the skin. It was sometimes possible to generate a tumour in

the muscle or on the mucous membrane, using the same substance. This suggested a common underlying nature of the most diverse tumours.

Repeating these experiments, Shabad and his coworkers noticed that benign growths, or tumours which do not adversely affect the organism, could be produced in exactly the same way. This observation indicated that harmless growths could sometimes have the same roots as grave diseases. This important discovery put surgeons on the guard. They became more suspicious of the capricious behaviour of tumours.

Several years later, Shabad's laboratory revealed new information in experiments with carcinogenic substances. One of Professor Shabad's colleagues, Dr. Morozenskaya, succeeded in causing cancer of the liver in mice by the same simple procedure of greasing the skin. The fate of chemical infective agents of the disease in the living organism gradually became clearer. They penetrate the skin, but do not stop at some site there, rather they wander about the body and come to a halt in their travels only when they find a receptive organ.

Shabad and his pupils did everything to publicize these little known carcinogenic substances. And doctors took notice. Hygienists dealing with air pollution in cities and towns became particularly interested in these substances. If anyone did, they knew the contents of soot and carbon black escaping from factory smoke-stacks.

Two Siberian towns—old Irkutsk and youthful Angarsk—became the objects of careful study.

Scientists were soon able to report some interesting findings. The two towns were, it turned out, breathing different air. And this was no poetical metaphor but the actual truth confirmed by precise analyses. The Irkutsk people at first could hardly believe that each person was inspiring more benzpyrene than many people together in Angarsk. Once convinced what the situation really was, the Irkutsk authorities started on a programme of reconstruction. Factory heating systems were rebuilt, the burning of coal and peat was organized so that combustion was more complete; dust and smoke traps were installed. In a word, a defense was thrown up against the uninvited guests.

This discovery found another application as well. Our chemical industry is producing more and more mineral fertilizers, items of perfumery, food additives, and other chemicals, which are first tested on mice. New substances are tried out on these bushy tailed "tasters" for carcinogenic properties. And these little beasts do not always approve of the chemists' work. Just a little while ago they rejected outright a dye called buttergelb that gave butter its pleasant yellowish tinge. We had to give up the yellowness because buttergelb contains carcinogenic substances.

The discovery was obviously useful, and Shabad was eager to continue the search in this promising direction. But there were doubts in his mind: Are tumours generated only by substances brought into the organism from the outside? He then set out to determine whether man might

not have his own native agents that cause unrestricted growth of tissue. This was a bold conjecture that needed careful verification. Shabad and his associates started out on a new series of experiments.

Day after day, an extract prepared from the liver of a man who had died of cancer was injected into the experimental animals (again these poor little mice). Eight hundred mice experienced the action of an extract that did not contain a single cancerous cell. Several months later when many of them succumbed to malignant tumours, Shabad was convinced of an important discovery: the organism can produce carcinogenic compounds independently, using local raw materials, so to speak. And there could be no doubt that such materials were available.

It had been noted some time before that the causitive agents of rodent cancer synthesized in vitro are chemically related to bile acids and sex hormones. If the body of a person constantly harboured substances similar in structure to carcinogens, there would probably be nothing unusual in Shabad's discovery. Yet there definitely was something new, and no small thing at that. The point was that this approach directed researchers' thinking towards a study of the fine and complicated processes that occur in the cell at the very inception of the tumour.

Scientists now have to investigate the causes of the origination of carcinogenic substances in the human body, figure out the mechanism by which they affect cells, and, finally, discover

means capable of containing the destructive growth of the tissue. The old truth that an early diagnosis of cancer is the best treatment has now taken on a fresh and concrete significance.

The substances which Professor Shabad and his colleagues have been studying for many years do not, of course, have a monopoly on malignant tumours. Unfortunately, they are not the only ones that can give rise to cancer. Various types of radiant energy are also capable of producing cancer.

Since the time of Pierre and Marie Curie, medical workers have been attracted to radioactive ore. It too is capable of transforming normal body cells into tumour cells, as witness experiments on animals and actual cases under production conditions. Yet radium is not only capable of harm; its invisible rays do us very good service at times. The rampant growth of cancerous cells, against which frequently even the surgeon is helpless, is often brought to a halt by a dose of irradiation. Thus, the killing ray, harnessed by the scientist, has become a ray of hope in the treatment of this terrible disease.

Magic Bullets

The offensive against cancer is mounting from all sides. Chemotherapeutists have joined surgeons and radiologists in recent years and have saved many lives, despite cautious remarks about the usefulness of chemicals in the treatment of tumours.

What an intriguing idea, to attack and destroy sick tissue in the most distant part of the body. Many regard this as a fairy-tale. Yet there is nothing impossible about it. Physicians have long since given up the erroneous view that substances which destroy cancerous cells harm the healthy tissue as well. They seek drugs that will strike only the target tissue. These "aimed" drugs have become a powerful anti-cancer weapon.

Where the knife of the surgeon and even the penetrating radioactive ray are helpless, one can try out numberless chemical compounds and find the sole one that is capable of destroying cancer cells. These magic "bullets" have already been cast, and are now being used against certain forms of cancer, but every year they will be hitting out against new targets.

Chemists in the Soviet Union and other countries have made several tens of preparations that suppress tumour growth, and this is of course not the last word. Surgeons were pioneers in the struggle against malignant growths, and are only too pleased now to put treatment of certain forms of cancer into the hands of chemotherapeutists. But nowadays doctors are working in unison. To save a life, it is sometimes not enough to cut out a tumour; the seeds that have already been carried to other organs must also be destroyed. Here new preparations are indispensable.

Cancer of the prostate that has metastasized to distant corners of the body occasionally succumbs to sinestrol and honvan; novomain salve can handle cancer of the skin; primary cancer of

the liver, which had been considered incurable, frequently gives way to sarcolysin, a drug synthesized at the Institute of Experimental and Clinical Oncology of the U.S.S.R. Academy of Medical Sciences.

Quite a few compounds have been found that retard the development of malignant diseases of the blood, the lymphatic system and certain internal organs. Particles of tumours carried by the bloodstream or lymphstream to distant parts of the body have always eluded the surgeon. Now they are being trapped by drugs using the same transport system.

The bloodstream is an excellent route for such "floating" medicines. Unfortunately, it too is rather defective: the bloodstream is too great and has too many branches. Milligrams of medicine are dissolved in the five-litre reservoir of the vessels and capillaries. They travel through every channel of the body, through the heart, the brain, liver, while the tumour, as often as not, is located some place in the left leg. The drug spends so much time getting to the site that it is frequently exhausted. And it is dangerous to increase the dosage.

The obvious question is how to cut down the travel time and get the drug to its destination along more direct routes.

You may have guessed what I have been driving at. Of course, the heart-lung machine. Here, it has found a new and unusual job: to circulate blood through diseased organs that have been switched out of the general system of blood cir-

culation. Say, the left leg that we mentioned may be transferred to an artificial blood supply by switching it into the heart-lung machine. The new closed system would then look like this: heart-lung machine, diseased organ and back again. The circulating blood in this circuit would be saturated with the required drug.

Note that our contour does not include either the liver or the kidneys. Which means that the drug is not acted upon by any outside factors and is not filtered out of the organism but is utilized completely—the full charge, so to say—against the target. And of course the dosage can be quite considerably increased without fear of consequences. The heart-lung machine has turned out a very promising instrument in the treatment of malignant tumours.

We shall come back again and again to this complicated, tantalizingly difficult problem of modern medicine, Problem No. 1. And you will see how many new ideas, bold conjectures and rigorously worked out experiments it gives rise to, how the very concept of the "anti-cancerous front" has changed, now taking in chemistry, mathematics, and electronics. One really believes that there definitely is hope that the short terrible word "cancer" will soon lose its sinister connotation.

IN THE DEPTHS OF THE LIVING

In England, in factories where there are frequent accidents, one can see signs like this: "Beware! God created man, but he forgot to make spare parts." Hidden in this macabre humour is the bitter truth. So far no one has ever been able to replace or reconstruct a mangled or diseased organ. And the chief difficulty here is not the lack of organs (for they might be borrowed from persons accidentally killed). Rather it is the stubborn resistance of the body to foreign organs and tissues. The human body rejects tissues not its own. And no matter how careful surgeons tie them in and stitch them up, they drop off in just a short time.

The human body does not even recognize relatives: a sick son cannot even accept the sacrifice of his mother. With the exception of uniovular (identical) twins, there are no two people on earth who can make such a gift to one another. Unique, like a fingerprint, the mosaic of protein molecules that make up the organism rejects everything that is foreign.

Scientists have constructed apparatus that sutures vessels and nerves, they have found antibiotics that hold microbes in check, but they

can't seem to overcome the principal barrier to unhampered transplantation of organs—the incompatibility of living tissues. The wiseman who said "I am a man and nothing human is foreign to me" could hardly have imagined how difficult it would be for physicians to implement his proud words.

But let us not trouble the ancient shadows. Take a look into the future of an intriguing idea—a "hothouse" growing of tissues and whole organs for use by humans.

The future of restorative surgery, what tantalizing potentialities!

I think that the very word "cure" will change its original meaning. There will be a time when diseases will lose their grip on human beings. We will then discuss not the temporary repairs of an ailing body, but a rapid and decisive extirpation of the very source of disease.

Exhausted organs, afflicted tissues will be radically removed from circulation and replaced by fresh, vigorous ones. Medicine will become a bank of health no longer making loans but paying out free grants. An exciting future for medical science. Let us take a trip into the future and pay a visit to the doctor.

Hours, Not Days!

The radio-eye flashed on in the admitting ward, and the duty doctor heard the familiar voice of the first-aid car: "In three minutes a fire accident

will arrive, a young girl with a third-degree burn." The voice stopped for a second, and then repeated a certain number twice and asked to have the operation room readied. Hardly had the first-aid helicopter landed on the roof of the hospital when three flat glass dishes were put before the surgeon. They contained the delicate rose-coloured skin of an infant. The doctor instantly checked the number of the dishes with that received by radio and began preparations for surgery. Three minutes later and the first "patch" went into place on the child's burnt body.

A new version of the live-water tale? No, not at all. Simply the inhabitants of this city had built a tissue bank: microscopic pieces of skin taken from their bodies were grown in special nutrient media and produced good yields. Anyone with a deep burn or wound immediately got a fresh patch of skin grown from those little pieces.

The numerous descendants of these isolated immigrant cells grew into excellent living tissue, which surgeons cut up into the patterns they needed. One might say that the order was fulfilled by material supplied by the client. This was true because the skin patch was his own, and not from anyone else.

In this way the inexorable law of tissue incompatibility was obviated. It was by-passed. If the laws of nature cannot be violated, it still does not mean that they cannot be circumvented by a clever manoeuvre. This will very likely be one of the solutions to this complicated problem

of the free transplantation of freshly grown skin. And not only skin, perhaps....

When first-aid crews bring in a person who has inadvertently swallowed a goodly portion of concentrated acid or caustic soda, surgeons have to make an artificial oesophagus out of his own intestines. It is a complicated and difficult operation, but the only way out. The mucous membrane is hopelessly burnt and there is no other way to save the patient.

No way yet, but there will be in time. In time, the burnt portion will be replaced by fresh tissue and in a week he will be discharged in perfect health.

Fiction? Yes, but not without a good foundation. Certain things have become fact already. Scientists today can grow living tissue on a nutrient medium in any desirable quantities. Only a consumer is needed. The trouble, however, is that this hothouse tissue is foreign: the human organism rejects it. And the chief aim now is to find a way to make them compatible, to penetrate into the secrets of the cell, to find the key to the protein code of living tissue. When that has been done, restorative surgery will surpass the most fantastic flights of fancy and then ordinary skin will be in the true service of man.

Then nothing, neither skin nor the cornea, need be taken from the dead. An opaque cornea of the eye will be replaced by a hothouse cornea, nice and fresh and transparent.

No longer will such extreme measures be needed as the transplantation of the skin of healthy

persons to a burnt accident victim. Because, unfortunately, such skin does not hold on for long. No matter how great our admiration for the glorious donors of skin, surgeons do not know of a single case when even a small part of it took.

Naturally, this is not to mean the sacrifice was senseless. Doctors transplant skin knowing in advance that it will be rejected, but time is gained, and that's important. This living shield screens the body from microbes and, what is most important, retains the proteins in it that pass through the burnt surface with amazing and fatal rapidity. When the danger zone is passed and restoration of the proper skin is initiated, the foreign skin will serve as scaffolding, so to say. Later the body will slough it off. It may appear like ingratitude, but in reality that was what saved the patient's life.

But first-aid requirements are broad, sometimes demanding such vital organs and tissues as a kidney or a lung. Naturally, surgeons cannot hope for such rich gifts, and like in the days of Hippocrates, doctors place all their hope on the curative forces of the patient itself.

This is not very comforting to someone afflicted with a serious ailment, but what can the doctor do, he can only alleviate but not cure. Yes, unfortunately, his powers are limited. But can't they be extended?

That is exactly what the new science should do, the science that deals with using an artificial nutrient medium to grow from a few cells or a tiny embryo whole layers of living tissue,

the various organs, glands—in short, spare parts.

The solution of this problem belongs to the future, but not the distant future, for scientists are already taking in their first harvest. One of the early fruits is a vaccine against infantile paralysis obtained thanks to the kidney-tissue culture of a monkey.

Not so long ago biologists growing living cells were looked upon, in the scientific community, as incorrigible visionaries. Their rejoicing, when a few milligrams of muscular or tegmental tissue were grown in a flask, was viewed as a joke, and reputable journals occasionally published reports of the seeding of living tissue as science curios. There was reason for surprise too. Investigators who for centuries had experimented on mice, rabbits and dogs, couldn't see how science could benefit from cells living in a test tube.

Years passed before the new science gained recognition, and the pioneering dreamers gained the glory of trail-blazers in one of the most exciting discoveries of our day. Most likely, today one could not find a single branch of experimental biology and medicine that disregarded the simple, cheap and all-penetrating method of tissue cultures.

These separate little cells far from the mother soil are helping scientists to catch the rabble-rousers that incite sound tissue to terrible action. They are helping to spot unknown viruses and

make vaccines against fatal diseases. It is hard to imagine what tomorrow will bring, what depths of the organism will be penetrated, and how many people's lives will be saved.

The new method does not only hold promise of deciphering the true nature of cancer, but also helps in the search, among a host of substances, for such that will be able to suppress this destructive uprising of the tissue.

The Seeds of Life

A malignant cell is a destructive individual. It disregards the laws that govern the growth of healthy tissue. To find substances capable of keeping it in check, one has to perform numberless experiments on animals. But when the drugs are finally found, we cannot be sure that they will be effective in humans. It is like looking for a needle in a haystack, one might say. And such was the case for a long time. But now the situation has changed radically. Malignant tissue is being put to work for humanity.

Tens of thousands of synthesized drugs and antibiotics are now being tested on bits of removed tumours. The diseased organ, now cut up into pieces and put into test tubes has become something like a gigantic trawler catching curative drugs among the chemical compounds. That is how the mutinous tissue was harnessed to the service of health.

But it is one thing to kill cancer in the test tube and quite another to do it in a living being. The

point is that malignant cells behave differently on artificial pasture land from the way they do in the organism.

A selected preparation is tested on animals. It must strike specific targets and not affect neighbouring tissues. If it passes these tests, it reaches the finals and is allowed to fight it out with a human tumour. This is the first snag. Who is going to permit a dangerous experiment to be performed on him?

The ideal model would be a cancer sufferer, but doctors couldn't even think of such a thing. So we have to go back again to the same old rabbits and mice.

The culture of tumour tissue came in handy here too. Only in this case it was grown in laboratory animals and not in flasks. This was no easy job and wasn't a success all at once. For many years scientists had failed in attempts to inoculate an animal with a human tumour—they were blocked by interspecific immunity of tissues.

A new preparation—cortisone—eliminated this barrier. It suppressed the resistance of the organism to foreign proteins. Using this potent hormone of the adrenal cortex, scientists compelled a piece of malignant tumour (a sarcoma removed from a patient) to grow in the body of a hamster. The cancerous tissue took very well in the host, which received a heavy dose of cortisone; it did not change and did not lose its human "touch". The sarcoma grows in the cheek pouches of the rodent just like it does in the body of the patient.

Now scientists are testing anti-cancer remedies on an animal in which a human malignant tumour is developing. This is a new approach to the study of cancer and it may lead to the desired results faster than other methods.

A disease that carries off millions of human lives must be conquered. There can be no doubt the day will come when, like poliomyelitis—that grave illness of children defeated with the same tissue culture—it too will succumb.

Nobody ever thought that the virus of infantile paralysis had such exotic tastes: it feeds only on bits of monkey kidneys.

The gastronomic fancies of the virus did not long remain its private business. When scientists first attempted to produce a vaccine against poliomyelitis, they needed its causative agent. No matter how much kidney stew the virus gobbled up, researchers satisfied every single whim. Reluctantly they spent tremendous sums in order to supply the virus with this expensive dish, but I repeat that a vaccine against an infection can be made only from its causative agent. Here it was necessary to prepare the vaccine for millions of children!

It is hard to say what the outcome would have been to this business if somebody hadn't recalled that the virus reproduces beautifully on kidney cells. These microscopic feeders were much more modest than their hangers-on and got on marvellously in the test tubes. The cells grew on a special nutrient medium, and the virus bred in them. Two kidneys were now producing five

thousand doses of vaccine! How this affected the finances, I'm not sure, but at least the monkeys were saved.

There are now laboratories that have no animals at all. Absolute quiet, no dogs barking—all the experiments are conducted on tissue cultures.

This is an extremely promising approach. A single monkey kidney now yields two thousand "experimental" test tubes, and the cell cultures prepared from two kidneys are yielding so many facts that a thousand living monkeys would not have been able to supply them.

For a start, that's not bad—a couple of monkeys doing the job of the whole Sukhumi Nursery. And if we recall that not only the polio agent, but also the viruses of the common cold, erysipelas, chickenpox, and many other diseases grow only on cell cultures, we will realize what a powerful and useful friend doctors have acquired in this tiny piece of living tissue.

The cell became a window looking out into the depths of life. The cell is used to study the laws of heredity and the biological compatibility of tissues, the causes of malignant growths and the whims of dangerous viruses—in a word, the entire complex and mysterious code of living nature. Yet, as if realizing its significance, the cell is making ever greater demands.

Hour by hour, day in day out special instruments attached to the microscope are recording an exciting motion-picture of this world. "From the life of a cell" it is called, and in place of film stars it shows the greatest mystery of all—the

division of the cell. This grips the audience. Before their eyes, living disks of matter swallow bits of food and digest them, they see how the nucleus and chromosomes inside the cell divide, especially the chromosomes, which are minute elongations that are believed to be the carriers of heredity. This is real life!

But to see is only part of the job. Scientists want to influence the course of life.

Operate the cell? Astounding, but possible, though difficult. Surgery of the cell! It already exists. Using a microscopic instrument or a narrow beam of ultraviolet rays, the surgeon detaches a single cell, which continues to grow in total isolation. The descendants of this single cell can generate a pure tissue culture. And if later we need a piece of skin or a mucous membrane, they will be prepared in just this way and in any desirable quantity.

At the Institute of Experimental and Clinical Oncology, an important application has already been found for microsurgery. The colleagues of Professor Alexander Timofeyevsky isolate a sick cell from a tumour and, by breeding it on a special nutrient medium, grow a malignant tissue. Using these pure-bred litters, they are studying the hereditary properties of cancer cells, their physics and chemistry—in a word, they are searching for the primal cause of the sudden madness of healthy tissue.

However, the cell is not the limit of microsurgery. Researchers have subdivided it, extracting the nucleus under the microscope. A little later,

a new nucleus was inserted. The operation was, as they say, a success. What was it done for? Microscale manipulations were not the sole aim. In substituting the nuclei of healthy and sick cells and isolating protein, scientists strive to penetrate into the machinery of grave illnesses, cancer being number one.

And while we're on the topic of the artificial growing of cells, I can't help mentioning future suppliers of hormones.

Hormone Plantations

We are quite used to regarding cows, goats, pigs, sheep as ideal factories for the production of milk, meat, and hormones, whereas in actuality these animals are very imperfect "machines".

Let's take a closer look at the cow. How efficient does it utilize its fodder in the production of meat? Nature built this "factory of beef" totally disregarding the interests of the consumer. This is quite natural, for increases in weight are only one of many processes occurring in the body of the animal. And not the most important. The continuously beating heart, breathing lungs, racing blood, and the intestines absorb enormous quantities of energy and proteins that might have converted the cow into a mountain of meat.

True, these organs are required to support life, to keep the cow, pig, and sheep alive, but for cell culture they are not needed. Here, there aren't even any wastes, which involve a consider-

able part of the food: the raw material is utilized almost in toto, energy consumption is negligible. Cells are relieved of emotions, they don't have to go in search of food, worms do not infest them.

Contagious disease and pestilence that carry off thousands of head of cattle are nothing to them, for the cultures are absolutely sterile. There is nothing extra, no frills, nothing—a colony of living and boundlessly reproducing cells does not even need a framework. And don't forget that the skeleton accounts for no small part of the weight of an animal.

This is an efficiency which even the inventors of the perpetual motion machines never hoped for. This problem would have probably been beyond the capabilities of biologists if chemists had not come to their aid: freely growing cells will breed on artificial food, synthetic amino acids. It is hard to imagine a better pasture land for cells than this, they will simply drown in food.

Here are potentialities without end for the housewife and cooking, for one can just as easily grow mutton as veal, or white and red meat, lobsters and crab necks, beluga and sturgeon. Here it is not only a question of delicatessen, but also of choosing the most nutritious foods. Turtle meat or crawfish may turn out more wholesome than conventional dishes. But let us return to the hormones.

So back to our plantation of hormones.

Along the way I saw a power truck with little cardboard boxes carrying the flashy names:

"Thyroid-17", "Pancreas-81", "Pituitary-3", then again "Thyroid". Which made me think that there must be cattle some place here. I had wanted to see how hormones are harvested from cell cultures like honey from combs, but here were ordinary apothecary items. "Nothing new," I smiled indulgently, "endocrine preparations have been in use since my grandfather's day." But let's see what's going in this shop.

From floor to ceiling I see enormous aggregates of coiling plexiglass tubes separated by narrow intervals, like stories, one above the other. It is difficult to imagine that these enormous coils function as minute vessels feeding the glands. But the thin layer of transparent tissue that lines the inside of the spiral confirmed our conjecture. Here, right next to me is a huge model of an organ of internal secretion. It may be a pancreas or a thyroid or some other gland—everything depends on the type of cells growing inside the tubes, for they, the cells, are what eject into the stream of nutrient liquid millions of medicinal doses of hormones.

I moved on. Scintillating beads of the purified preparation were settling down on the glasses of the stills. Another few steps and I saw mountains of the live-saving ampules containing rime-like hormone crystals. A fascinating picture, but I wanted to know what was in those boxes.

This is the way I figured it: there is no sense using the pancreas of a sheep if one spiral here yields as much insulin as a herd of one thousand head of cattle. I soon learned the actual situation.

The glands in the boxes are human glands and not those of sheep and calves.

Naturally, no one made a present of these adrenal glands and pituitaries. They were taken from patients. Two or three cells of an impotent pancreas taken from a diabetic patient and that was enough to breed a big piece of endocrine tissue that relieves him of daily insulin injections. The thyroid gland, the adrenals and pituitary have lost their monopoly situation in the organism, for excellent substitutes have been found for all of them. The incredulous look of the reader is probably turning to suspicion.

Sorry, this story is my imagination from beginning to end. But fiction though it is, every step is buttressed by facts. Just take these calculations. A short time ago the weight of a tissue culture was measured in tenths and hundredths of a gram. Now, fifty-gram cell colonies are being grown. Which means that within several years the weight gain has increased by a factor of thousands!

If this rate holds for a few more years we will be turning out kilograms and even tons of tissue. Cells on this artificial diet never have food problems and there is no limit to their growth. The main thing is to produce the food. Then fancy will become fact.

Thus a piece of living tissue starts its journey from under the microscope into the test tube and from there into factory vats, where it will be converted into chunks of meat. And, finally, a few words about the pancreas.

The lives of thousands of diabetic patients depend on cattle—the chief producer of raw material for endocrine preparations. What will happen if a natural calamity decimates the flocks of sheep? Most of these patients have to take a daily dose of medicine that replaces a vitally important hormone. We wouldn't need to pose this lugubrious question if there weren't experiments where glands of internal secretion are being successfully grown in test tubes. True, so far it is only the parathyroid glands.

A few years ago they were transplanted under the skin of people doomed because of a deficiency of the parathyroid hormone. A third of the patients were saved and are alive today. Isn't this proof of the boundless potentialities of science?

I won't be surprised if surgeons began replacing a section of the heart afflicted with infarction with a muscle tissue specially grown for the purpose. And perhaps we will even be able to.... But that's for next chapter.

The Heart of an Eagle

Yes, just that, and not the heart of a dog or a monkey is what I shall dream about when mine grows weary or beyond repair. The dog's is of no use, only lives 10 to 15 years or so. And the monkey too, though related to humans, doesn't live much longer. Now the eagle is something quite different. Fantastic endurance! It lives up to a hundred years and the heart is in perfect order as it wheels through the skies, no heart

trouble, no coronaries! This strong long-living heart would be a true and reliable friend of man. The eagle's heart is certainly something to dream about. But how feasible is it?

In a recent article, an eminent experimenter wrote: "It is still early to speak about replacing the human heart and lungs." Early, but not hopeless. For again the principal difficulty is the antagonism between different kinds of tissue. If this antagonism is ironed out, man can then conclude a "cordial alliance" with any animal: biologists will suggest the best choice, and surgeons will put it in place with stapling devices. As far as animals are concerned, the situation is indeed quite some time off. Meanwhile attempts are being made to implant human organs in man.

As we have already mentioned, such transplantations are possible only between identical twins. The kidney of a brother transplanted to take the place of a diseased kidney saved the life of one American boy. The common system of blood circulation had unified their bodies long before birth. This rare success had, to some extent, been prepared by an interesting observation of calves. When born with merged placentas, they readily accepted skin grafts from one another.

Investigators got the idea of repeating this freak of nature in an experiment. By sewing newly born mice together, they succeeded in eliminating tissue immunity for some time. The paws of the little animals were exchanged, and they lived for a long time never suspecting that they weren't their own.

With humans, of course, the situation is much more complicated. The substitution of a worn-down organ is sometimes the only way out. And surgeons have frequently had to do such operations. But in all fairness it must be said that success has been rare. Even when there is a volunteer, the patient cannot accept the "gift". Nature puts its veto down and the tissue doesn't take.

True, the fraternal sharing of paired organs has already saved a number of lives. But these cases are few and far between. Exceptions that merely prove the rule, and—I would hasten to add—that are pregnant with new discoveries.

For example, a young Czech biologist Gašek succeeded in making close relatives out of a turkey and a hen. He united their embryos at an early stage and now these chimeras are rather guaranteed from accidents and diseases because the protein enmity between them was overcome.

After these experiments it became clear that the biological peculiarities of tissues start developing already in the womb of the mother. This was a very important and depressing discovery, for transplants are needed for elderly people and not embryos. An experiment like this one is not possible with human beings. In future this may be one way of surmounting the immune reaction. But a new and shorter way has been found.

If it is impossible to adapt the patient to foreign organs, this does not mean that the reverse will never be attained: make the organs fit the body

of the patient. The training will of course have to begin early, when still embryos, including the future host in the bloodstream and there we'll probably have substances circulating that suppress protein hostility of tissues. Such organs will indeed be of the same blood and flesh of the patient. Nurtured by him, they may find a secure place as substitutes for lost organs.

Am I carried away by my dreams? Organs growing outside the human body? Hardly imaginable, yet such there are. The embryo of the tibial bone of a chick was seeded on a special nutrient medium, and a real bone grew up with all tubercles and condyles. The embryonal pieces of skin continued to grow in a glass dish and even sprouted tiny hairs, as if confirming the fiction of hothouse patches. An eye embryo even produced all the parts of the eye: iris, retina, and crystalline lens.

Embryonal cells have even grown into a heart muscle! The heart muscle not only grew up, but even contracted like a real living one. And all of this was possible due to the fact that right here the embryo of another tissue was maturing—a cover tissue, which at first glance could hardly be suspected of such an influential role. But precisely the muscle fibres of the heart growing alongside it behaved as if in the mother's womb.

This remarkable partnership is of course not the only possible one. Other, even still more interesting combinations of different embryos are possible. Varying such neighbours, scientists will be able to penetrate still deeper into the

secrets of youthful, developing tissue. And after thoroughly exploring them, they will learn to control its growth at will, and put together organs, sculpting living life.

But that is the future. Much closer and more accessible are organs bred from embryos. Here, expansive vistas open up limitless opportunities, one of which is the dream of the eagle's heart.

I foresee the day, not too distant, when new medical institutions—"tissue and organ banks"—will be opening up in cities and towns. These banks will store large supplies of skin, mucous membranes, muscles, bones, glands, and, possibly, even hearts. A new science will come into being—substitution surgery.

The riches of such repositories will never be exhausted, for the growth of each cell proceeds in a geometrical progression, producing innumerable progeny. The bank will never fail.

Today, a number of countries are building up supplies of tissues for use not only by experimenters but by surgeons too. The time will come when there will even be banks of human organs. The holdings of such banks will go to sustain the dearest of all things—health and life, and where there is life there is hope.

Here is where I wanted to terminate my story of the future, but I was interrupted by the present: encouraging news arrived about a successful graft of foreign tissue. This was the first success after a long search and much disappointment. Our dream is being realized. And I, yesterday's

dreamer, must catch up with reality. Today, things are being done faster than the tale can be told.

But how was the vigilance of the living organism tricked, how was his age-old squeamishness about outsiders overcome? By accident. It always happens that way to those that are ever searching. He's lucky, they say. This time the discovery commenced with a piece of bad luck.

A Ray of Hope

No explosion, no pain, no blood. They stood unprotected near the atomic reactor when the instrument pointer suddenly twitched, signalling ON! The body was instantaneously penetrated by enormous dosages of merciless rays. No one felt anything, yet each knew for certain that death was imminent.

Can it really be so simple? One of them didn't want to believe it and rushed to a particle counter of radioactivity. Yes, everything was predetermined: first the hair would fall out, then fainting spells, then the catastrophe of blood formation, and finally the end. It was on a September day in 1958 in the dull silence of their laboratory that six Jugoslav physicists inadvertently overstepped the threshold of life.

Six is a small number, but when the next word is "men" it takes on immeasurable proportions.

Late in the autumn they were taken to Paris. Doctors at the Pierre Curie Institute were hard at work on the problem and did not hide the truth:

only one could hope for mercy, the rest had received several times the fatal dosage of irradiation, which knocked the bone marrow completely out of commission. The skin, muscles and bones were hardly touched, but the delicate bone-marrow cells which every day mint hundreds of thousands of millions of blood corpuscles were doomed. The rays had destroyed this marvellous mint and, with it, all hope of recovery. Blood cells do not live much more than one hundred days. And man succumbs earlier, deprived of the source of constant blood regeneration.

Blood transfusion? Yes, of course, that will undoubtedly alleviate the situation. Alleviate but not alter: the transfused blood corpuscles succumb faster than the original ones. What is more, they represent a foreign protein and according to a familiar law, the organism straightway enters into a struggle with them. This load wears out the sufferer very soon.

Potent antibiotics are hardly able to repulse the onslaught of microbes. But even this powerful anti-bacterial shield is not able for long to replace the white blood corpuscles which received the main blow of atomic radiation.

November came, the last month of life. Neither transfusions nor anti-microbial preparations helped any longer. The main store of blood was exhausted and was hardly at all being replenished. When death was only a few days away (this had been calculated very precisely), the doctors decided on their last trump. The dying men were wheeled into the operating room.

The Director of the Institute, Professor Mathé would attempt a transplantation of healthy bone marrow. The audacity of this step was obvious, but there was nothing more to lose. He struck out against the nature of living tissue, for victory would mean triumph over death. What could the Professor hope to achieve? Did he really intend to refute the law of immunity?

Hardly, Mathé knew the strength of protein enmity. But he also knew something else as an experienced clinician who had taken part in experiments exploring a way to a compromise, to a brief if even bad peace. True, that had been far removed from human beings. The heroes in these scientific communications continued to be mice, rats and guinea pigs, yet every experimenter is well aware of the chasm that separates man from these "unknown soldiers" of science. Mathé's aim was to bridge this gap. He was supported by one interesting fact.

Researchers had long known that irradiated mice readily succumbed to the meekest microbes. Radiation, like cortisone in the case of hamsters, drastically reduces the immunity of mice to infections. It reduces the immunity virtually to zero. Under such conditions every microbe is a dire threat.

One should recall that microorganisms are minute protein bodies. Yet they lived on in the body of the irradiated mouse. The point is that irradiated bone marrow ceases not only blood formation but also the production of antibodies—the defense proteins that reject all foreign matter, from a virus to a whole organ.

Then why not take advantage of the absence of antibodies in order to inject into the sick and nonresisting organism the life-saving cells of bone marrow?

The conjecture held promise. It was followed by a simple experiment with two participants, a healthy rat and a mouse, subjected to a fatal dose of radiation. Fresh bone-marrow cells were extracted from the tibial bone of the rat and injected into the blood of the doomed mouse.

Days, then weeks passed and the little fellow felt fine, as if nothing threatened his life. And he was saved—the inoculation was a success. The rat cells roamed about the bloodstream of the mouse and found their destination. They settled in the destroyed bone marrow. Not in the liver, or the lungs, but only in the bone marrow!

Having found their true master, the new cells immediately set to work. Just two weeks after transplantation they felt so much at home that they completely replaced the irradiated bone marrow. The mouse became a rat in the best sense of the word: every element of its blood was rattish.

This was the first successful experiment in total substitution of bone-marrow tissue destroyed by irradiation. And it pushed the French physicians to an audacious decision. Four volunteers gave their bone marrow for transplantation. A fine steel needle was used to extract it from the tibia. The anesthetized donors were just coming to when the marrow had already been transplanted to the victims of radiation sickness. Now it was a question of waiting.

Waiting and doubts are the perpetual associates of great discoveries. Pasteur, after inoculating the Smolensk peasants against rabies here in Paris nearly a century ago, spent many sleepless nights. Years later, his friend Ilya Mechnikov suffered pangs of remorse near the bedside of a stableman who, following the Russian scientist, drank a potion of diluted Vibrio comma. And in distant Bombay, doctor Vladimir Khavkin lived in constant anxiety over the lives of millions of Indians that he had inoculated with an anti-plague vaccine which he had first tested on himself. And in the Pierre Curie Institute they waited....

One died. But then after this death a miracle occurred. Every day more and more potent and viable corpuscles appeared in the blood of the remaining Jugoslavs. The bloodstream gradually and slowly built up its valuable load. And then finally the day came when both doctors and patients could see that death had retreated! Nobody would die any more.

The transplanted cells had taken. The organism had submitted and welcomed these foreign bodies. The rays that had destroyed the bone marrow and suppressed blood formation, also overcame the immunity to foreign tissues. This disaster brought with it the seeds of salvation. Science had compelled the death-dealing rays to work in the name of life.

The first success is the mother of hope, and it loosens the reins on one's imagination. Again we revert to transplantations. The bone marrow

took—maybe other tissues will too, perhaps even whole organs? I would so much like to say yes, but there are still many barriers.

It is no intricate problem to reduce immunity by large doses of radioactive rays. However, as we have seen, such irradiation is not completely harmless, for as immunity falls so also does the formation of blood. The danger is far too great.

Closely on its heels comes yet another menace—cancer. Rays generate a multitude of tumours in experimental animals. Again too much of a risk. And, finally, it is very important to know how strong the connections will be that link the patient with the newly acquired organ—antibodies might disrupt such bonds when immunity is restored....

What is that squeaking I hear? Oh, yes, our little mouse! The radioactive one which lived on for some time with transplanted cells despite all my reasoning. How do we account for this?

It was all very much simpler with the mouse. What it did was to borrow the rat's bone marrow. As soon as its own marrow was restored, it threw out the alien bodies. The mouse no longer needed foreign tissue, for blood formation was restored together with the bone marrow. And although the antibodies waged a fierce struggle with the transplanted cells, the mouse was in complete safety. The resurrected bone-marrow tissue set about stamping its own blood corpuscles. In short, in such transplantations, immunity and blood formation are two ends of one stick: one strikes the mouse and the other helps it out of trouble.

But it doesn't get out completely. It wasn't so easy for the mouse to rid itself of this "gift". The rat's bone-marrow cells that had given the mouse its blood now themselves began to generate antibodies against it. It was a fight against the host organism that had been so kind. The visiting cells got to fighting with the real owner, the mouse. Chased from their habitat, they resettled and calmly set about their usual job of generating antibodies.

This outcome could have been foreseen, since the mouse was also a foreign body as far as these gift cells were concerned. That being the case, the laws of immunity set in, and the immune bodies produced by the rat's cells attacked their new host in her own home.

The mouse came down with secondary radiation sickness. This is one of the most dangerous complications accompanying the transplantation of bone-marrow tissue. And it is as dangerous to humans as to experimental animals.

Now everything was clear: transplanted cells are a two-sided sword, at times acting against the host himself. So researchers are busy hunting for ways of relieving the organism of transplanted blood-forming cells up to the critical moment when they cease being dear friends and turn into bitter enemies.

However, let us return to our radioactive mouse. Rather sly of it to look down on outside help when it began to feel self-supporting again. This was a lucky coincidence. But the other organs, unfortunately, cannot count on it. If they fall off, there are no substitutes.

I can see the grimace on the reader's face. The old story again: first congratulations, then condolences. Take it easy, dear friends, there is still hope, and a good deal too. The successful experiment in Paris promises to wipe out certain grave diseases of the blood.

Scientists are now aiming their atomic artillery at cancer of the blood, leukemia. This is also a disease of the bone marrow. As if out of its mind, the bone marrow throws enormous quantities of white corpuscles into the blood. The avalanche of leucocytes squeeze out the red corpuscles and life too.

The only way to halt such an attack is by bringing in radioactive rays: they destroy the source of the trouble—the bone marrow. True, the malignant cells die and so do the normal cells, but that is a necessary sacrifice. It is a guarantee that not a single grain of cancer is left in the body. This is the virgin land that will accept a fresh and healthy bone marrow taken from donors or animals. In time, when we have learned all about the breeding of these temperamental cells, they will be grown artificially, like the skin "patches" we talked about at the beginning of the chapter.

Biologists have penetrated into the mysteries of the cell and are turning their secrets to the good of humanity. There will be a great holiday of science when protein molecules are conquered, for they are the basis of life.

Proteins are not only the food of man; they are, above all, the man himself, his muscles, organs, and the catalysts of life, the enzymes. When medical science learns to control protein reactions and the growth of tissue, it will take hold of a powerful method of regeneration of the human organism.

But the cell is important not only to biologists and physicians; it is the prototype of the chemical factory of the future, which will cover only a small piece of territory but it will carry on a superprecision sequence for the assembly of protein molecules. The technology of a microscopic blob of living tissue is marvellously organized and remarkably straightforward and simple, proceeding at ambient temperature and normal pressure. The productivity of the cell is something fantastic. This chemical "factory" turns out, at one time, proteins, carbohydrates, fats, hormones, enzymes and a host of other substances that are brought into the production cycle right off. And all this requires the very simplest of raw materials. Good food for thought for the biologist, the chemist and particularly the engineer. The automatic system of the organism can serve as a brilliant illustration of what industrial automation should be like.

When man saw a cell he began to meditate about the great mystery of the regeneration of living tissues. A more profound study may lead him to an understanding of life itself. Then he will become its true master.

Part Two

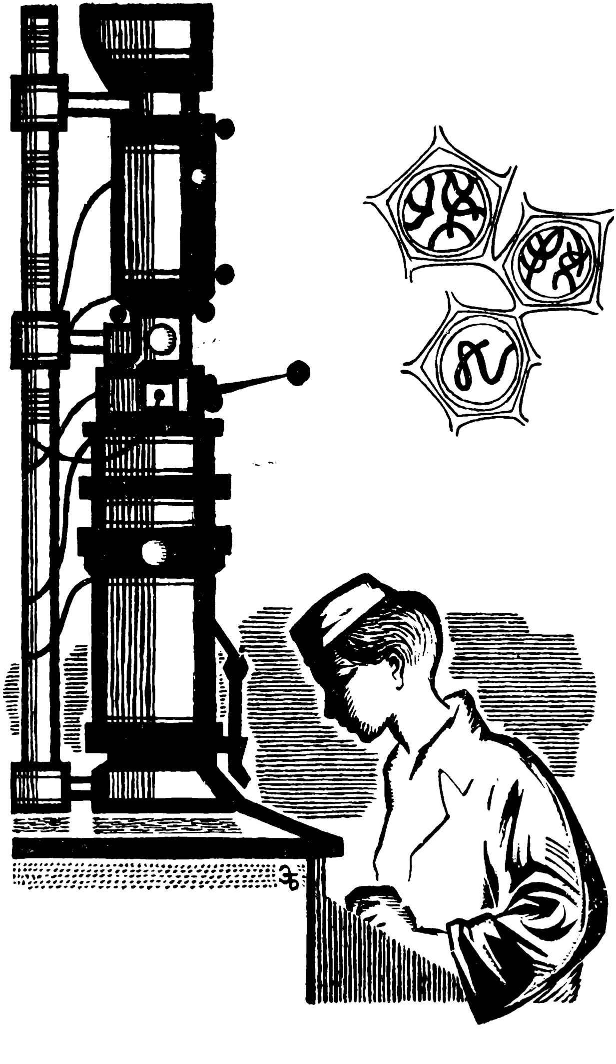
The Treasure House of the Cell

In the forefront of science are biology and medicine, energetically assaulting the bastion of living nature—the cell. Within its delicate mechanisms lie the mysteries of life.

What is the essence of immunity and grave illnesses, how can hereditary characters be controlled, who incites healthy tissue to destructive insurrections, how does a muscle contract, and, finally, what occurs in the delicate and mysterious structures of the brain? These and other difficult questions will, we hope, be answered by a new and rapidly developing field called molecular biology.

Up till now, researchers have studied the designation of each organ and tissue and have sought to learn their primary functions. They have produced what amounts to a detailed map of the basic physiological processes. But that only answered the question "Where?" Where a certain blood corpuscle or hormone or enzyme is formed; where a certain reaction takes place that heats the body; where its source of energy and construction materials are found; and, finally, where they are consumed.

Now scientists want to learn how these complicated multistage reactions take place in the body, and what is the pattern of the ultimate building blocks of the organism—molecules of protein.



NEVER GROWING OLD

Envy sometimes acts for the good. Man envied the bird and learned to fly himself, he watched the fish and developed the ocean liner. The airplane, the submarine and even the multistage rocket are all fruit of good envy. Time and again, an idea taken from nature is revived in refined metallic structures. There is nothing unusual in this, of course. Only the transmigration of souls is mysticism, ideas are readily transportable. But occasionally there are things that will amaze the most hardened reader.

The Anatomy of the Eiffel Tower

When I learned that the Eiffel Tower has a direct connection with the microscopic study of living tissue, my immunity to all sorts of discoveries fell—I was astounded. More amazed still would be the French engineer Alexander Eiffel, the man who constructed this steel monster out of twelve thousand girders, if he were told that he hadn't thought up anything at all original but had only repeated a structure that nature had created numberless times. When Eiffel hurried to complete the project of his Tower for the opening of the Paris World's Fair of 1889,

he had no idea that the best design had been thought up long before.

We can easily imagine how surprised this talented engineer would have been to hear that he himself was carrying a ready model, rather his tubular bones were. The femur or, if you wish, the tibia. All joking aside, this is one of the best verified truths established by biologists: the structure of tubular bones and the pattern of the Tower coincide exactly. Even the angles between the supporting surfaces are precisely like those between the cells of bone cross-bars.

The bones are made to the specifications of the Eiffel Tower, one might say. However, he himself unwittingly was nothing more than an imitator. It may be that his famous Tower owes its longevity to this very unusual similarity. In this case, engineering thought reached the extreme perfection of a living organ that has been refined for millennia.

The risky conception of a young engineer and the long scrupulously thorough labour of nature. What do they have in common?

It is not merely an external similarity. Strength and light weight are the two gods that builders have worshipped from the very start. Therein lies the unusual community of this metallic structure and living bone tissue. Eiffel's creation with its swift rise skywards and the human bone that can support a weight of half a ton are both constructed with extreme economy and strength. Not a single extra part, yet those few that do the job are loaded to the maximum. In a word, both

Tower and bone are designed in the best style with no needless frills.

It certainly is difficult to decide which to prefer: the insight of an engineer who has created a technical wonder, or the engineering ingenuity of nature.

The Tower I knew rather well from photographs, but I still don't know the bone at all well enough. The geometry of bone tissue is a rare piece of symmetry and harmony. Everything seems calculated in strict accord with the most rigorous mathematical laws. And yet almost nine tenths of its live weight can be disposed of and it will still support the customary loads and even more. The supporting part of the skeleton that holds our whole body does not even come to ten per cent of its mass.

I stood in amazement and wonder at the refinement of an organ constructed with such an enormous reserve of strength utilizing minimal quantities of building materials, and then this: less than 10 per cent! What of the rest? Is it indeed superfluous?

There is nothing extra in the bone. Everything is there and needed. Every element has its designation. The framework supports the body, inside the tubular bones, like in a tunnel, lies the blood factory—the bone marrow. Here is where millions of corpuscles are produced every second. We've already been there but let us take another look. Blood formation is only one of many interesting activities which take place there.

Bone is not only the support and casing. It plays a much more important role as well: it

participates in the calcium metabolism of the organism. And calcium is life itself. If there is a deficiency of calcium in the blood, life is endangered. Surgeons know this from the bitter experience of operations on the thyroid gland. Ordinarily their finale is tragic.

When the doctor cuts out the gland together with the subcutaneous cellular tissue, he does not have time to sew up the wound before the muscles of the patient are caught in sudden spasms. Then death ensues. Surgeons were at a loss, they altered the operational techniques, but as before patients succumbed when the scalpel touched the thyroid gland. They continued to die until it was learned that doctors were also removing the adjacent small parathyroid glands that handle calcium metabolism. Surgeons had not noticed them before, yet the organism reacted violently and immediately to this loss.

The bone is constantly and generously giving up its calcium to the blood. It would be more exact to say that the blood itself washes the calcium from the surface of numerous crystals impregnated in the bone tissue. The enormous deposits of this "bone ore" have made the bone a sort of monopolist in calcium metabolism. But there is never a let-down. The ore always comes to the surface as expected. Loaded with this valuable substance, the blood delivers it to all corners of the body.

And still there is not enough of this calcium that the blood licks off the crystals. The deficiency is a microscopic portion, yet enough to kill the strongest man.

Here is where the bone shows up its generous nature. It dissolves in the blood and makes up the deficiency. The dissolving process gets going in a big way: every minute several hundred grams of bone pass into the blood plasma. Figure it out, while you have been reading this chapter, your body has dissolved about one kilogram of "bone ore", almost like sugar in a glass of tea. But don't be frightened, you won't melt away altogether. The organism has a very powerful machinery of self-regeneration—your fate will not be that of a little snow-maiden in spring.

Our story is going to be about the constant breakdown and buildup of the parts of the human body, of its incredible capability for making up deficiencies and losses, and repairing worn-out parts—in a word, about the inexhaustible well of living tissue.

What People Live by

Machines can do much. They are now strong, even "brilliant". Yet their creator continues, like in the old days, to train his muscles in order to break a record just the smallest portion of a second, or a few centimetres, or half a kilogram. Yet I feel hurt when I hear the sad words "Man is not a machine!" Of course he isn't! He is constructed a hundred times better than the most powerful machine of the most perfect design. And it is not at all a matter of the fantastic efficiency of the living cell, such as engineers can only dream of. For even this dream is on the way to

reality. The organism has an inimitable property, compared to which the best qualities of steel, concrete and plastics are nothing.

No matter how refined these materials become, they cannot be made into a machine that can repair its own failure. While the human body is constantly—from birth to the last breath—engaged in the regeneration of worn-out tissues and organs. Miraculously, it does not even need to be stopped for repairs. Old parts are thrown out, new spares are put in and—what is particularly important—without a hitch and without a stop. An exact copy of the broken part is inserted in its place. A muscle will never dislodge a bone; skin will always replace skin—a cornea will never take its place.

At first glance this might not seem so exceptional to the reader. Yet the organism is no made-to-order institution with fashions analyzed and materials specially bought. The most motley assortment of tissues is restored at its own expense and in many cases out of the same starting materials. That is why, if the surroundings of the embryo are altered, new flesh suddenly grows up.

If skin epithelium is transplanted to the cornea, it does not become a cataract but a thin transparent membrane. The eye it glasses over does not differ at all from its mate: after transplantation the skin acquires the properties of the cornea. On the other hand, there will never be any such confusion if it is grown from mother tissue. Here, all the neighbours will restrain it from being unfaithful. And the young tissue, curbed by

adjacent tissues develops exactly like its predecessors. It grows up fitting into the accepted pattern and replacing the lost tissue.

Unfortunately, not all tissues hold the secret of constant regeneration. It is known only to the hardest working and most short-lived parts of the body. Among these are the bone marrow and the blood.

This is a very pleasant exception. One can easily imagine what the situation would be if the blood-forming organs did not possess an incredible reserve of restorative forces. Human beings would live a little longer than a Maybug: childhood for two weeks, youth another week, and three to four weeks of adulthood—that would be just about all, and then time for death.

There is much truth in this melancholy joke: the life of a red blood corpuscle is only about three and a half months long. That would also be the human span of life, for without blood cells there is no life.

Here is our fatal formula: man lives as long as the weakest of his vital organs.

Yet there is no fatalism.

The blood cells are indeed rather short-lived. They break down rapidly and completely. But they are born just as rapidly. Every day the bloodstream sees one thirtieth of the red corpuscles replaced. Fresh cells are constantly replacing those that die off. Also regenerated is the oxygen carrier of the blood—hemoglobin.

The reserve of blood corpuscles considerably exceeds their depreciation period. This surplus

can generously make up for loss of blood on the field of battle and on the operation table, at the donor station, and in accidents.

But the blood is not the only important part of the body. How do the other no less valuable elements replenish their losses? Not all of them have such good credit. Now, at last, we probably have found the weak link. No, nature has again taken precautions. Most of the extremely responsible organs are made of extra-strong tissues—muscle and nerve. The heart, the skeletal musculature and the fourteen and a half thousand million nerve cells of the brain work without letup. They just don't wear out. And if it weren't for diseases caused by outside factors, the mechanism would tick on for at least one hundred and fifty years.

Yet it appears that even the "eternal" tissues have retained some kind of a right to self-regeneration.

Many have heard of the experiments of the Soviet biologist Professor Alexander Studitsky on the restoration of the skeletal muscles. But not all know that his laboratory has also studied the heart. Study is not the word, they grew it.

The embryo of the heart muscle of an ordinary chicken conducted itself, on the laboratory table in the hands of scientists, just like the legendary Phoenix bird: it too, one might say, rose out of the ashes. The embryo of a chicken's heart cut up into minute particles, cells, again grew up on

the membrane of another embryo and pulsated without halt. This was a living model of the heart. But not only muscular tissue is capable of regeneration.

Biologists have their "atom" as well. It is the nerve cell. For many long years it was considered indivisible. For living tissue, this meant a total inability to grow. Whence the inevitable conclusion: man is born with a live-long store of neurons. Nerve tissue was likened to a legacy which can be used up but which can never be increased by even the slightest amount. No one questioned this eternal truth. The brain was the brain, and there was nothing to be done about it.

But then a Moscow graduate student, Sui-Tsin, working on animals made an interesting and promising discovery. After an accident, she saw how cells of the cerebral cortex—the highest division of the nervous system—divided. Before her very eyes the impossible occurred: a nucleus of a neuron divided into two. Even physicists could envy a discovery like that. For if it turns out that the delicate cells of the brain divide, even if very slowly, and grow, like other cells that belong to the less noble tissues of the human body, then medical workers will in time learn to control this process. It may be necessary to speed up the reaction of nerve tissue to the intervention of the scalpel, or to retard it. Then neurosurgeons and, possibly, psychiatrists will be able to treat many grave illnesses. Of course, it is still a long way to restorative surgery. That is a science of the future and Sui-Tsin has taken the first step.

Another advance was made by the American research woman-scientist Geiger, who grew a large colony of nerve cells on an artificial nutrient medium. Several neurons which she took from the brain cortex of a dead person have been living and reproducing for quite some time. And although it is hard to be sure that no interstitial cells of the brain were reproducing, the very existence of a culture of growing nerve tissue, which had always been considered "sterile", was added proof of the great restorative resources of the organism.

The Lymphocyte Builder

Phagocytes are indefatigable microbe hunters. Their battle deeds—familiar to all—are "die, and thus assert life". The body needs defenders, but it also needs builders. And here interesting new features come to light about these white corpuscles. They have a peace-time profession as well. Every fourth one is engaged in creative work. It is born in a special lymphoid tissue of the spleen and the lymph nodes, whence the name lymphocyte. This modest toiler for a long time kept his extra job in the dark. Scientists first suspected something when they noticed a surprising loss.

Out of every thirty new-born lymphocytes, only one gets into the bloodstream, the others vanish without a trace. They cannot be found either in the blood or in any other tissue of the body. This was readily detected. But it was quite another thing to explain why. A search began.

The lymphatic glands naturally had a great multitude of lymphocytes—their birthplace. Then control posts were set up at two main streams where the entire daily produce of the lymphoid tissue flows. Again swarms of lymphocytes. But all trace of them was lost. Where had they gone to? Perhaps they just melted away.

That, by the way, was not precluded.

Lymphocytes may perish for a just cause. Disintegrating in the body tissues, they give to them their flesh, which contains a very valuable substance—ribonucleic acid.

A part of the white corpuscles apparently are constantly delivering this acid to all parts of the organism, like the red corpuscles do oxygen. But in working for life, they themselves perish, for they disintegrate in toto. This is precisely the sacrifice that has to be made in order to release ribonucleic acid, which takes an active part in the construction of body proteins. The building of these blocks of life is no less vital or complicated than breathing.

Now a lymphocyte will probably not give way to a red corpuscle when they meet, for scientists have given it a promotion.

But it is too early to put on airs, for this is only a conjecture about the side-line profession of white corpuscles. A bold and interesting conjecture that enables us to peer into one of the Top Secret mechanisms of the self-regeneration of living tissue.

Many observations have accumulated on restorative processes in other parts of the body. Some

of them are fresh, just out from under the microscope. Others ... but judge for yourself.

Prometheus and Monkeys

The ancient Greeks were more interested in mythology than biology. But one of the heroes of Hellene, strange as it may seem, has some relationship to the problem of the regeneration of internal organs. You may recall that the vulture which consumed the liver of Prometheus never fulfilled Zeus' order. The enraged god in vain sent him to the Titan, for he did not know that the liver is capable of building its cells (even whole lobes) anew. Today, not far from Mount Caucasus where the mythological vulture unsuccessfully laboured, real and very cogent experiments have been carried out.

In the Sukhumi Nursery, monkeys have had large pieces of the liver removed. Even cut in half, it soon restored its normal volume. Surgeons were not left indifferent to this observation, for liver complaints have never been very amenable to surgery. But now that connective tissue is seen to grow rampantly, the surgeon is not so reluctant to pick up his knife. Sometimes a whole lobe is taken out. As a result of this operation, connective tissue in the remaining parts is gradually resorbed, but the liver tissue grows, the cells enlarge and together with them the functional area of the organ also expands.

In the old days, doctors were wary about removing a kidney, fearing that the other one would

cease to function. Today, the surgeon operates the only one left and is quite confident that even a fourth part of this small organ will in a year or two become a full-fledged cleanser of the human body. For regeneration of bone, one doesn't even need a fourth or a hundredth part, it grows up on a clean spot. A clean, disinfected spot is what is needed: when neither microbes nor disintegration products from some focus of inflammation impede restoration.

This time the surgeon clears away the whole organ and not just a piece. If a bone is suppuratively inflamed, he removes it completely from the periosteum and inserts in its place a gypsum rod, and then sews up the wound. The gypsum remains in the living periosteous jacket. This is a rather strange thing to leave in human body, but a fresh sound bone will grow up around it.

Out of what? Don't worry, there are materials enough about. The surgeon took care of that. He was merciless with regard to the sick bone, but took immense pains to keep intact the healthy periosteum, which will resurrect the lost organ abiding by all the rules of the builders' code. Again, we see that the organism itself does all the restoration work. With good reason physicians are more and more relying on the reserve forces of the organism. They are indeed life-giving.

But belief is not enough, we've got to learn to ferret out these spares of life and skilfully utilize the riches stored away there.

The medical profession does not, naturally, hope for a universal method of combating disease.

Anything that aims at curing all ailments usually doesn't cure a single one. But the discovery of the secret of regeneration of living tissue promises to wipe out many of them. Note that diseases of the heart, the vessels, the blood and the nervous system are frequently due to the breakdown of this mysterious mechanism. To grasp this process means to cure the patient.

A difficult but intriguing problem. How can we resolve it and find the cherished keys to health?

The Best Operation

The clue is hidden deep in living tissue, in its complex and sometimes strange interrelations with neighbouring tissues. Their "friendship" starts in the embryo. Growing up side by side, they take a liking to each other. This partnership restrains rampant growth, regulates and directs it into certain channels. Which is very true, for they rarely violate the regulations of their institution. But if a single link is broken and customary bonds are ruptured, the tissue straightway breaks with tradition and goes over to the enemy camp. That is how bones grow out of ordinary connective tissue, for instance.

This is not done on the sudden either, the entire life cycle of bone cells is covered to the minutest detail. The newly converted tissue takes upon itself all the duties of the bone tissue: it is immediately included in calcium metabolism and it starts up the formation of blood—in a word, it

does not let on in the least about its unusual origin. But who got it started on the new path?

The chief culprit of this strange transformation is a tiny piece of mucous membrane taken out of the urinary bladder or the kidney pelvis of an experimental animal. When this disturber of intratissue placidity is about, the connective tissue gets terribly excited. When transplanted nearby, it grows in deep and fast and makes it change both appearance and functions. But every cloud has a silver lining. After this drastic change, the ordinary supporting tissue takes its justified place right alongside vitally important tissues. Now its foremost task is the building up of reserves of calcium and red and white blood corpuscles, which, as we know, are not among the least important things in the organism.

Here we discover yet another possibility of regeneration of life. The most valuable of tissues may be grown to order in the body itself at the expense of neighbouring tissues. Luckily the usefulness of this substitution is much greater than the loss. And the law of protein incompatibility does not hold here at all: the blood-forming tissue that originates out of its own cells is not foreign to the organism and gets along fine with all its neighbours. They don't care a whit for the magical transformations, the main thing is that the tissue is theirs.

That is one more way of by-passing the tissue hostility. No transplantation, just grow the valuable tissue in situ.

The body itself occasionally takes to this peculiar internal loan. The patient first seeks aid from within before going outside. A broken bone usually partakes of the generous periosteum, but frequently covers the deficiency of building materials from nearby connective tissue. Then the bone callus grows rapidly and firmly.

Unfortunately, the emergency service of the human body does not always function so energetically and independently. It is frequently dozing when the body is threatened, say by such a mortal danger as radiation of the bone marrow. A radioactive blow knocks out the blood-formation system, and the machinery of the ancillary setup can't get under way. Though there is no end of connective tissue in the body, it is not put to use to restore the blood factory. An order is needed for things to get moving. That is the function of transplanted tissue or perhaps some chemical substance that it releases—to give the order.

So far, such authority has been found only in the mucous membrane of the urinary tract. In its presence, timid connective-tissue cells turn right into bone. Really, neighbours do differ. But the medicos rejoice, they hope to make use of this discovery, which will teach them new methods of treating refractory fractures, grave diseases of the blood and metabolism.

There are probably tissue catalysts in other parts of the body as well. When scientists discover them, it will be possible to control the growth and restoration of a variety of organs. When they

straighten out the subordination of tissues, they will make them toe the mark.

Then the human body will be repaired on the go, with a definite guarantee and without the knife. An age-old dream will come true—no ageing, no wearing out of organs, and no dealings with surgeons. No matter what surgical techniques are devised, the best operation is that which does not need to be performed.

VIRUS OF MANY GUISES

Ailment in Seven-League Boots

This is influenza. It stalks through the land, across whole continents, state boundaries and quarantines, across mountain ranges and ocean expanses. No sooner has it cropped up in Singapore, than it is found in Turkey, then it is found decimating the Persians, Egyptians, and on the rampage in Indonesia, approaching Australia, and dropping parachutists in Nigeria and Chile, attacking the cities of Europe and America. The taiga and the jungles, the tropic heat and the polar cold, equatorial rains and the dry winds of the steppes are no barrier, as it crosses all climatic zones.

Between the spring and autumn of 1957, this seven-league killer held the entire world at siege. Over one and a half thousand million persons succumbed to this sticking disease, tens of thousands never recovered. The epidemic gripped the whole globe. When at last it subsided, people were left dazed. There was food enough for thought. We have conquered the plague, smallpox, cholera, yet we are still at the mercy of the whims and vagaries of influenza viruses. It is not that these minute microorganisms have been neglected, not at all: the whole matter lies in their unusual properties.

The flu might be said to be playing an unfair game with humanity. Unlike many "honest" infections that leave behind a long-term solid immunity, this one only leaves bitter recollections. The influenza virus is stingy when it comes to souvenirs like immunity. When it leaves the organism it does not burn its bridges like the germs of smallpox and the measles, which strike man once in a lifetime, but leave only a feeble and short-lived trace of immunity—a precaution peculiar to all recidivist microbes. But occasionally it turns against the microbes themselves.

When the flu strikes, the defensive mechanisms of the body come into action. They gather their forces and at last begin to counterattack. The virus loses its chief stamping grounds—the body cells in which it ordinarily breeds begin to destroy their tenants mercilessly. Without shelter and food, the virus perishes.

But the interesting thing is that they do not die out altogether, but are saved by human beings. As soon as people acquire immunity, the virus develops a different, unheard of variety.

Aware of imminent death, the virus exhibits incredible resourcefulness. It alters the protein structure of its shell and soon appears in a different guise. Unidentified, it starts life anew. Viruses may not know about Darwinism but they certainly utilize natural selection to the utmost. They even enlist human beings, for it is man himself who, against his will, selects the most stable forms of virus and tests them out on

himself. What is the cause of the remarkable viability and shattering force of the influenza virus?

Vladimir Gavrilov, scientific worker of the Institute of Virology of the U.S.S.R. Academy of Medical Sciences, carried out an experiment to check this. If the virus actually does change in nature, why shouldn't it exhibit the same tendencies to metamorphoses in a laboratory experiment, say on white mice. So he inoculated them with small doses of the influenza virus.

The little animals sneezed and ran a temperature, but were rewarded—in a month they developed an uncommonly strong resistance to the disease. Hundreds of thousands of fatal doses of the virus did not produce the slightest effect. Their lungs teemed with microorganisms, yet they calmly went along nibbling at their food. And though the virus reproduced at a fantastic rate, the mice thought nothing of it, they remained sound as a bell.

Then Gavrilov repeated the experiment. He killed several of the immune mice, crushed their lungs and fed the material to the next group of inoculated animals. The microbe succumbed again, and the mice did not come down with the disease. Gavrilov used their lungs, in turn, for further inoculations.

This operation was carried out again and again, each time putting the virus through the lungs of the rodents. But the experimental mice stubbornly refused to get ill. Then after nearly a hundred such duels, the virus suddenly acquired

a killing force. It decimated the mice which just before had been totally indifferent to it.

The antibodies which the mice had developed against the virus could no longer contain it: they were the same, but the virus had changed. On the sly it had built up a store of vicious qualities and had suddenly become a potent, active infectious agent. Now the scientist was sure of one thing: the aggressive nature of the virus was toughened in these constant skirmishes with the defensive forces of the organism.

Independently of Gavrilov and even somewhat earlier, this problem was taken up by a Leningrad woman-investigator, Tatyana Luzyanina. The results of their researches coincided. And a few years later, the conclusions of the Soviet workers were corroborated by the American microbiologists Gerbar and Lusli. This was experimental proof of the variability of the influenza virus under the influence of immunity—the chief cause of numerous epidemics.

The microbe sets into action the most powerful defensive mechanisms of man. The organism throws its elite troops of immune bodies into the fray. They destroy the enemy relentlessly. But in this mortal combat, a strong and dangerously new type of causal agent is generated. Cause and effect change places and the battle is resumed. The virus and man remain at swords' points.

For a few years, human beings serve as a living proving grounds for viruses to perfect their destructive properties until one of them is born

fully adapted to the new conditions. That is the progenitor of a new generation of disease agents. In two or three years, this fledgeling virus grows into a continent shattering epidemic. Fifteen to eighteen years later it matures into a globe-rocking scourage, and since it differs drastically from its progenitors, it stalks the world virtually unhindered. The immune forces of human beings are not able to withstand the onslaught of this new type of virus, which, like a juggernaut, rolls on to a world-wide pandemic.

That was what happened in the spring of 1957.

The Enemy Attacks

Influenza came out of hiding all of a sudden. In March it appeared in the north of China, ripped across the entire country and in two weeks was raging in the south. From here it plunged deep into Asia, and in two months the continent was caught in an epidemic. When a few weeks later the disease gripped Australia, Africa and America, it was clear that Europe would not escape.

On May 4, the World Health Organization received the first signal of disaster. Singapore was struck by the virus infection and gave warning of its tempestuous onslaught and unusual force. Epidemiologists suspected this to be a new unknown type of agent.

True enough, the virus isolated from Singapore patients was radically different from its predecessors, and serum obtained from the blood of

persons who just recently had the flu did not render it harmless. It did not contain any protective proteins—antibodies—against this virus. The serum was resistant only to those viruses that it had fought against, which meant that this was their first encounter. This corroborated the first conjecture of medical workers.

Another important proof soon came from the laboratories. The newcomer was not like any of the viruses of earlier epidemics. The serums of animals infected with all known flu agents were helpless against this type, for this was the first encounter.

Having suddenly and drastically altered its biological features, the virus got out of hand for some time. The surprise attack was irresistible. This advantage of the enemy was sure to give doctors no little trouble.

The many-guised virus complicated their problem immensely because—among other reasons—it did not use ordinary transport facilities. It travelled by air between sick and healthy, dispensing with the common carriers of infectious diseases—blood-sucking insects. These intermediate keepers of microbes frequently enable medical workers to break the chain of infection.

The viral agent of yellow fever vanished with mosquitoes; malaria too does not last long with them. Plague fleas and typhous lice have long since been tracked down. Here, epidemiologists could not apply their tried and tested method. The influenza virus found a reliable shelter in man.

The cells of the mucous membrane of the respiratory tract are something like an incubator for viruses. Here they find everything they need to reproduce. Cellular protoplasm serves as excellent raw material and is virtually gobbed up. In two hours or so the descendants increase by factors of ten and more.

The young follow in the footsteps of the old. Penetrating into healthy cells, they devastate the proteins.

Adapting the food stores of others, the virus ensures itself an affluent life. In a cell, it could indeed consider itself almost invulnerable. But it was precisely here that scientists at last found a way to destroy it.

First of all, they spotted a characteristic feature of the virus—it is very unhospitable. Once it has occupied a cell, it does not allow any of its kin to visit. It locks its new dwelling with a special key, the enzyme of its own membrane. This complex chemical substance helps it to enter the cell but at the same time does not allow it to have any other tenants. The bridge that lets the virus into the protoplasm is then burned, as it were, and any other homeless brethren are left out in the cold.

True, the tenant does not use its home for long. Numerous progeny soon leave it. The damaged bridge is reconstructed and the cell is again ready to accommodate a new tenant.

This time, scientists suggested that the mucous membrane invite different tenants, harmless viruses that would lead a quiet life. Then when the

onslaught of flu viruses began, the bridges would be destroyed and the cells of the mucous membrane would all be occupied with harmless lodgers. Thus turning away the unwanted guests, man finally rids himself of them completely.

Very tempting to have such controllable immunity during an epidemic! It would save tens, hundreds of millions from the disease and many human lives. The human toll is often very great, in fact the criminal influenza holds the world record: the incidence of influenza exceeds that of all other infectious diseases taken together. No matter how low the death-rate of this fleeting illness, the toll of human life is great in years when it is rampant.

Virologists aim at breaking the grip of this scourage. They have long cherished the intriguing idea of obtaining a potent vaccine. But this requires a better knowledge of the idiosyncrasies of the virus. Then they can be turned against it.

But where is one to find harmless lodgers for the mucous membranes? Scientists decided that the best thing would be to utilize this same virus.

Microbiologists have known for quite some years the protean character of the natural causal agent of the disease. Time and again it was observed to change before their very eyes. The chameleon virus disappeared only to appear again in a different guise some time later. Here is where medical men figured they could turn this variability to good use.

They wanted to obtain a vaccine from an attenuated culture of the virus. Therefore they were particularly interested to know whether it could be made to change on order and under laboratory conditions. This kind of domesticated type would breed in the mucous membranes, yet would not cause the disease but rather immunity to it. It would go through a dress rehearsal with the organism so that when the real agent came along there would be nothing to fear.

Biologists have already remade quite a few microorganisms. But the influenza virus is a special kind of creation. Is this scatterbrain capable of expiating his sins?

How the Virus was Tamed

Scientists in the Soviet Union and other countries had carried out interesting experiments that aimed at determining how the flu agent behaves in captivity, whether it can be domesticated, made to work for man. This is naturally no easy job but the hunter must know the habits of the beast he is after. Virologists were on the look out, for they knew that their opponent was more cunning and insidious than the worst of the forest dwellers.

Once in the hands of scientists, the virus began to serve science. Researchers loosened an important secret: as in Gavrilov's experiment, the virus built up forces against rodents and at the same time lost its ability to afflict humans.

This discovery enabled biologists to turn the pathogenic properties back. Here was a convenient method of producing an attenuated withered strain of the virus.

One of the first experiments was made back in the thirties by the prominent Leningrad microbiologist Professor Anatoly Smorodintsev. He bred the flu virus in the lungs of mice and obtained a live vaccine which he used successfully on human beings. However, a great deal of raw material was needed to make the vaccine. Rodents are not suited for this purpose. What is more, their lungs proved to be not a very appropriate incubator for the virus because other viruses got mixed in. What was needed was a nursery with warmth, ready food and immaculate conditions.

The problem was complicated but scientists found a clever way out. They suggested a special diet for the virus—chicken's eggs. The virus is injected into a chick embryo, where it multiplies with amazing rapidity. The main thing, however, is that it loses its virulence. The egg shell ensures sterile conditions and the embryo supplies the nutrients. Simple and cheap. Five cubic centimetres of liquid virus culture is sufficient to infect thousands of eggs, which in two days will supply litres of vaccine.

However, the virus must first be trained before it starts to multiply. Quantity means nothing if the virus is indifferent to humans. The microbe for the vaccine must always be somehow related to the future host so that it shouldn't slip past

and should remain in the organism for "rehearsal".

Here, they shook hands by correspondence—the virus was grown on the cells of the human mucous membrane living far away from their "home land", on a special nutrient medium. This exotic food did not change the attitude of the wild-growing cells to the virus. They were just as hospitable in laboratory dishes as at home in the nose and throat. Again the lone cells came in handy. Ten to twelve seedings from one dish to the next, and the virus feels at home. It can now be used to make a vaccine on chick embryos.

The multiplied viruses are sucked out of the eggs into special chambers irradiated with ultraviolet light (this precaution keeps out all foreign microorganisms). Now, finally, the pure vaccine sealed in ampoules may be delivered to the battle front.

But this vaccine is capable of wiping out only a known virus. Yet new varieties born in the struggle of old viruses with man attack millions of human beings for the first time. How are they conquered?

Counterblow

From Singapore came alarming news, and Soviet medical workers began preparations to meet the newcomer. The time factor is important in combating flu epidemics.

The chief advantage of the opponent is sudden attack. Workers on the health front made every

effort to combat the epidemic since it couldn't be prevented.

Over 25,000 hospital beds were readied. Antibiotics, chemical preparations and serum were brought into the cities. The army of doctors and nurses was reinforced by volunteers of students from medical institutes and colleges. Then the battle began. The anti-flu-centre headquarters of the Ministry of Health of the U.S.S.R. received regular reports from the "battle fronts" concerning all enemy manoeuvres.

But physicians lacked the chief weapon—a vaccine against this new Asian virus. Only a vaccine could deal a telling blow. Virologists immediately got to work on a new drug.

But it was not so easy to tame the wild beast. First of all, it refused to multiply in cell cultures. Since time was pressing, that was given up. The loss of a single day meant thousands of new cases. The Influenza Study Centre set up in the Soviet Union received information from the World Health Organization on advances of the new pandemic wave over the European continent. It was expected in the U.S.S.R. by the autumn of 1957. Not much time for training the virus on human tissues. A new vaccine was needed then and there and in millions of doses. And they were produced.

The virus was taken from patients and grown only on chick embryos. It fought back furiously, but after many seedings it finally lost its virulence. Then it was put into production. The vaccine was dried in a vacuum apparatus and airplanes

carried it to the far corners of the country. During the pandemic, fifteen million doses of the vaccine were turned out—a really astronomical figure. Three million doses were used and in some places this drastically cut into the epidemic wave.

The drug proved to be tough, but unfortunately, it is not suitable for everyone. Infants, for which influenza represents a graver danger, find the live vaccine a difficult hurdle. They are treated with antibiotics and serum taken from the blood of inoculated horses. The viruses are fought by the antibodies of animals. But a human being, even the youngest, must have his own defensive shield against the disease. That is what the workers of the Institute of Virology are now trying to produce.

They hope to develop in children an active immunity in two stages: first with a harmless killed virus and then with a live virus. This problem will be resolved when scientists succeed in building a complex vaccine in the form of a drug combining attenuated pathogenic agents of diphtheria, whooping cough and influenza. This vaccine would ward off several diseases at once. But medics have other difficulties as well, which are no less complicated.

To make a good vaccine, the physician must know exactly what virus attacked. The old maxim that one must know his enemy is particularly relevant here. A preparation made according to rules may prove useless. No immunity will result if the vaccine is not based on the virus that

causes the disease. Yet it is frequently very difficult to detect the virus.

For a long time it has been usual to identify microbes by their attitude towards specifically known serums: they react only if closely related. Knowing the serum, it is easy to determine the related microorganism. But this method requires a great deal of time and does not always yield the proper results. Scientists are on the hunt for new, more dependable and faster methods. A recent proposal is a new technique for identifying viruses by means of luminescent antibodies.

Painted with a fluorescent material, these immune bodies of blood serum are becoming something like labelled atoms or "bloodhounds" inside the living organism. They search out their viruses and combine with them, giving them away hands and feet, so to say: in the ultraviolet rays of his microscope, the researcher immediately identifies the bright point as the antibody with attached virus. This luminescent "tag" greatly speeds up the hunt for our invisible enemy.

Work continues on the anti-cold vaccine begun by the well-known Soviet virologists Professors Victor Zhdanov, Anatoly Smorodintsev, Valentin Solovyev, and Mikhail Sokolov. The pandemic is over, but the virus is still alive. It is simply hiding out in nature, biding its time and preparing its destructive weapon for a fresh attack. But now there is hope that this time we will not be caught unawares. Medical men are on the job.

World-wide anti-flu centres disseminate information about the slightest skirmishes with the virus. As soon as the newcomer is identified, any fresh features are made known to all neighbouring countries. This dangerous decimating scourage has taught the peoples solidarity. During big epidemics, the agent is the same no matter what the country, and so we must fight together.

A TRIP INTO THE MUSCLE

When Archimedes asked for a point of support in order to move the earth, he surely had in mind also the strength of human muscles.

Indeed, how does this small organ operate, where does it get its lightning-like speed, tough resilience and strength?

The muscle is a special type of engine, but has nothing to do with steam power or jet propulsion. Yet at work and in battle it is what makes man strong. Even the atomic reactor will not eclipse the glory of the human muscle. And not merely because it has done everything that we have here on earth, but also because it is no worse than any motor. It is even built more solidly and economically. Though machines are all the vogue, muscle mechanics offer a great improvement over steam engines and turbines.

I am fully convinced that a machine patterned after the muscle will in time become one of the most powerful mechanisms in our industry, transport, even in the home. Why would we need cumbersome washing-machines and floor-polishers if we had light-weight, strong and manoeuvrable mechanical "hands" and "feet"?

Once, machines ousted hand labour and effected a revolution, the present return of engineers

to the muscle does not mean a technical counter-revolution. The latest alloys and plastics fashioned as living flesh will in our time produce a true wonder of technology.

However, it is not only a matter of technical novelties. Machines are not everything. Studies of muscles promise much more than the most powerful and refined mechanism—they promise health and, at times, life itself. Yes, even life! For the very simple reason that today over half the people of the world who die succumb because the heart muscle suddenly fails. Where can we find a spark to make the heart blaze forth from smouldering life?

In the heart. And this is no metaphor either. The key to the heart lies deep inside the heart muscle, and only there. To fathom the heart has proved more difficult than to reach the bottom of the ocean. The pulsation of the heart—a movement just as simple and natural as a smile, a sigh or a handshake—has turned out to be mysterious in the extreme.

Though ready to respond to the slightest whim, it stubbornly resists every effort to decipher its delicate mechanism. Yet to disclose it is tantamount to taking over control of one of the most important systems of the human body. That is why the anatomist, physiologist, biochemist and biophysicist are concentrating so much attention on the muscle fibre. They want to know what is happening deep within it at the instant of contraction. Yes, what does happen?

A Miracle of Molecular Technology

Strange as it may seem, when the muscle contracts there is no change in the length of its fine ultramicroscopic fibres. Yet it does get shorter, as anyone knows who has seen a frog's leg jerk when a current is passed through it. There would be no motion without contraction.

So the muscle fibres do not contract, yet the muscle as a whole becomes shorter! Where is the hitch? These two verbs are practically synonyms and yet this sharp contradiction. The muscle is certainly endowed with an interesting mechanism. It is worth looking into.

This was made possible just recently when the electron microscope opened up to investigators the fantastic world of protein molecules. Since then, muscle mechanics has been considerably clarified. It could no longer keep its secrets from the electron. So let us go along into the depths of the muscle.

But before going on this trip let us take a look at the muscle under an ordinary microscope. The first components are hundreds of fine close-lying fibres. Slashed with transverse bands, they look like a stretched out tiger skin. The bands are so close together that one can't help blinking. But if one takes a steady look, he will see that the skin is covered with villi—tiny hairs: it consists of a great number of still smaller fibres called myofibrils. That is how the largest sections of muscular architecture appear in the round field of the microscope.

A muscle consists of fibres, and each fibre is a bundle of stretched out myofibrils. Under ordinary magnification it simply looks like a multiple-strand cable. That is as much as the eye can perceive. Beyond that begins the mysterious world of hyperfine structures. These are visible only in an electron microscope.

Here the field is different. It resembles a bird's-eye view of a familiar place. The alternation of bright and dark lines, of light and shade gives way to continuous strips. The muscle would appear to have split up its land into hundreds of tiny plots. In each one of them, biologists have detected utterly new features—the tiny filaments of muscular proteins, which one might term the ultimate screw in this complex living mechanism. This is exactly what was needed in order to shore up a very interesting conjecture about the nature of muscle contraction.

The English microscopist Huxley, who had spent no small number of hours in the study of the muscle, conceived of an amusing idea for representing each myofibril as a long box-like body filled up with tiny guns. These he charged—mentally, naturally—with arrows. An arrow in each muzzle. The butt plays no role, only the muzzle and charge—prototypes of some kind of ultramicroscopic parts of the myofibrils, which the scientist had hypothesized. What happens in the box when the muscle contracts?

You've guessed it: all guns fire at once! No, dear reader, they do not. On the contrary, they load up and the arrows slide into the muzzles.

And as they go in—note this—they contract, as it were. Why "as it were"? Simply because there is no actual reduction in length of the arrows but rather a shortening as they move into the muzzle, like one's neck when the head is pulled into the shoulders.

That is shortening without contraction, if we may say so. Now imagine that there are hundreds of such well-geared mechanisms operating at once in each ultrafine myofibril. And everything is done on orders, in sequence and rhythm. Rather intricate, yet very close to the truth, as it later transpired. Comparisons are all right, but let us get back to the flesh.

The Hungarian biochemists Ferenz Straub and Albert Szent-Györgyi found two proteins in it: actin and myosin. These proteins were later found to be the ultimate muscle motor.

Actin molecules are roundish and mobile, like drops of mercury. If a little potassium salt is added to them, they immediately form short chains that straightway link up into a single long and fine filament like a column of mercury.

In each myofibril, these filaments are stretched taut. And there are very large numbers of them. They are packed together forming little stories that connect their short links. An electron microscope shows even transverse rows that cross straight longitudinal lines. The muscle is criss-crossed with them, like plotting paper. Actually these lines have crossed out all earlier pictures of the muscle. In structure, the living flesh turned out to be very much like a crystal.

In this elegant molecular structure nature made use of yet another protein—myosin. It is not as fine as its mate, but it has a definite place in the myofibril. The myosin rods are located strictly between the actin filaments, as if the tow had been combed into minute fibres. A strand made up of two kinds of thread, silk and coarse—that is myofibril made up of tiny chains of actin and myosin.

The real secret of muscular contraction lies in these two proteins and is based on the fact that neither actin nor myosin can contract by itself. But together, as actomyosin, they suddenly acquire the remarkable capability of rapid, almost lightning-fast contraction. The noted Nobel Prize Winner Albert Szent-Györgyi once confessed that the most exciting moment of his scientific career was when he first saw actomyosin contract.

But why did Huxley rejoice? Did it really matter what proteins there were in the muscle and how they were arranged, crosswise or lengthwise? No, the Englishman kept his hands on these protein chains for good reason, for the filaments of actin represent the "arrows" used to load the imaginary gun-muzzles, while the myosin rods between them apparently play the role of the muzzles. In contraction, the actin filament slides along the rods like skis on a ski track.

The reader may think we are going too far astray—all guessing and conjectures. How about some facts?

True, true enough. Facts are the air of the scientist. Now just imagine the astonishment and

joy of Huxley when electron micrographs showed two clear-cut uniformly alternating types of filaments. A living embodiment of his conjecture. The electron microscope had put down a firm foundation for his hypothesis, which virtually "hung" on these newly found protein filaments. This was now the most trustworthy theory of muscular contraction.

Such was the secret of the muscle. Not the twisting of protein molecules into spirals or folding accordion-fashion, as scientists had long supposed, but just ordinary sliding lies at the heart of muscle mechanics. Like the runner of a sled, the actin filament slides in between the rods of myosin. Moving into the rods, it becomes shorter. All this occurs almost at once, otherwise how is one to account for the lunge of a football goalkeeper, the instantaneous start of a bird, the hundreds of flutters a second of the wings of a tiny insect?

It certainly is a clockwork mechanism that nature has devised. Unfortunately, biologists haven't yet been able to get a clear picture of what happens. Every motor requires fuel; no matter how intricate its workings, not a single gear will move without fuel. Coal, petrol, electricity, or the fissioned atom. What does the muscle use? Where does it get its tremendous force, where is its storehouse of energy, in short, what happens at the moment of peak tension?

The Fire of Life

A few years ago Szent-Györgyi performed a simple yet elegant experiment. He asked the question: What moves the muscle? To find the answer, he destroyed all movement. He took a piece of rabbit muscle and wetted and froze it, thus depriving it of the capability of independently contracting. The living machine came to a halt. It lay dead on the table, indifferent to any stimulus. Now the search for the fuel that drives it could begin.

Very cautiously the scientist dipped the strip of muscle into a solution of potassium salt. He waited a moment and then added magnesium. And finally, pressed out of a pipette a droplet of some light-coloured liquid. The muscle immediately came to life! It contracted so strongly and suddenly that it could easily have lifted a load a thousand times its own weight. That was a record! The rabbit wouldn't have been able to squeeze out any more. So what is this magic droplet that puts so much energy into the muscle?

Adenosine triphosphoric acid, or ATP for short. Only three letters, yet in biology they are weightier than many words, for this was a great discovery.

ATP is a storehouse of living energy. Each component particle of phosphorus (three altogether) contributes a small charge of energy. Together, they build up quite a perceptible load. The instant the muscle gets the order to contract,

this peculiar storage battery generously gives up its entire store of energy. The muscle mover goes straightway into action. But in doing so, the ATP is broken down. Such is its purpose: break down and release energy.

Where does this Niagara Falls of energy go to? What mechanisms does it set into motion in the muscle?

With a magic substance like ATP, biologists could now begin to probe smaller units, for instance the muscle fibre called myofibril. It contracted fast. Yet that was not the limit. When the Hungarian researcher excitedly followed the shortening of the actomyosin filament, the ATP faithfully supplied it too with energy. "This," thought the scientist,"is one more proof that the protein chain is the smallest model of the simplest contractile system—myofibril."

In this way, biologists gradually got to know the mechanics of muscle movement. The energetics was much more difficult. It is no easy job to trace the transition of chemical energy into motion and still more difficult to do that at the molecular level of a living organism. Still, certain things have been figured out.

In order to give up its store of energy, the ATP reacts with muscle proteins, more precisely, with one of them—myosin. It is not known how this occurs. As yet, no one knows whether they join up into a temporary chemical partnership or whether, like jugglers, they bandy charged particles (ions) back and forth. But the fact remains that ATP transfers its charge to myosin.

And the interesting thing is that the myosin forces itself to accept this valuable gift.

This property of myosin was discovered by the noted Soviet scientist Academician Vladimir Engelgardt. Together with Militsa Lyubimova he discovered, in the muscle, the trigger device of the energy reaction. It turned out to be—would you believe it?—the muscle fibre itself, the myofibril. This hard worker is always on the job. It even finds its own food. It puts its own protein—myosin—on the job as enzyme to induce ATP to break down. It is always at the trigger of this complex and probably multistage reaction.

This is as it should be: the muscle should not rely on enzymes imported from other tissues, because too much is at stake, too much depends on the reliable work of the muscle. Of course, it would be a great risk to leave the fuel problem to someone on the side: some wandering enzyme might not show up at all when most needed. Obviously, self-service is the best system. That is why this myosin was charged with a second and no less important task of breaking down ATP.

This was a big discovery.

Engelgardt bridged the gap between the chemistry and the mechanics of the muscle. From here biologists started their penetration into the mechano-chemistry of muscle proteins. There, a perfidious question lurked: How, after all, is the invisible energy converted into a visible contraction, what ultimately moves the actin and myosin? Conjectures there were, and no small number of them, but for the time being scientists were

silent. No one was in a hurry to express himself. Work went on and thinking continued all in silence.

Huxley was quiet too. His hypothesis had one very vulnerable spot: it failed to account for the force that compelled the actin filaments to slide between the rods of myosin. Indeed, why is it that in a contraction the actin moves into the myosin and is then again released? Huxley did not know. But he did know that if the theory is true, every new discovery should confirm it and illuminate it.

Such a discovery was soon made. At first it puzzled biochemists. To their surprise, the myosin molecule was not the smallest particle of the muscle. It possessed ultrasmall features with a rigorous distribution of duties: some picked up the energy from the ATP, others utilized it. It was likewise found that myosin is a very "sociable" protein. It readily reacts not only with ATP, but also with its partner actin. A curious motley of facts. No few hypotheses were shattered by these facts, but for Huxley they were a boon.

For the hundredth, maybe the thousandth, time he mulled over this mystery of the muscle. "Where does the sliding come in and why? That is the bare statement of the problem. Now what have we to work on? Very little, unfortunately. Myosin takes energy from ATP, then reaches over to actin ... and finally links up with it.... Stop! Isn't this the solution? Of course, bridges resolve the whole problem. The prime mover of muscular contraction is in the form of temporary cross-pieces between two proteins...."

It was probably not that way at all. But the electron microscope confirmed the fact that Huxley was right—a muscle did have bridges. The young Soviet microscopist Vladimir Gilev was able to photograph these intramuscular cross-pieces.

They throw over a link from each actin filament to a myosin rod and pull the filament in, as it were, using the energy obtained from the ATP. Each new bridge was a step that actin took along the myosin. The step was even measured. It came out to 55 100-millionths of a centimetre. Not so big. But it was certainly a big step forward in the study of the muscle. Scientists now knew for a fact that the chemical reaction is converted into a muscular contraction.

It might appear that everything was now clear. But it wasn't. Ahead lay an ocean of unknowns; the journey into the muscle had just begun. The path lay from the molecules of contractile proteins to smaller particles, electrons. They are the ones which apparently play the main role in energy transfer to the executive mechanisms of this remarkable living machine.

Electrons are fast on the pickup, they are excited instantaneously. These are the properties we need in order to account for the amazing rapidity of muscular contraction. All superfast reactions in the muscle are ultimately dependent on the indomitable energy of excited electrons.

But this quite unexpectedly brings us to the threshold of a new science—quantum biology. We have nothing much to say about it, for quantum biology is a science of the future.

Quanta and life. They indeed look strange thus juxtaposed. Just a little while ago we saw the advent of molecular biology. Not everyone was happy about it. Now here is the living energy of electrons, the thermodynamics of the muscle. Unfathomable, one might say. Yet this is the fresh untrodden path where investigators hope to comprehend at last how energy controls life.

But then there is the question: Who controls the energy? Something must give the signal for muscular contraction—pull the trigger, so to say. Do I see a smile? Why, of course, the motor nerve. True enough, a nerve, more precisely, a nerve fibre. But how does it do the job? It is like a log among peas, this fibre among the muscle molecules.

Pulsed Messengers

It is a marvellous yet definitely established fact that there is no direct connection between a nerve and a muscle. The electron microscope just recently debunked one more old delusion. A nerve does not go into a muscle like the roots of a tree into the ground, but stops right at the threshold. All attempts of microscopists have been to no avail, there is no contact. Ultrafine sections of tissue have invariably yielded the same picture: myofibrils are separated from the nerve fibre. Its branchlets do not get lost in the muscle mass but just press lightly onto it like short fingers into a glove. The glove is the boundary line: the nerve does not go any farther into the muscle and is separated from it by a special partition.

Strange indeed. There is no connection, yet an electric pulse finds no difficulty in jumping between them. Something along the lines of a wireless telegraph system?

That is what some were already thinking when it transpired that the engineering genius of nature had been underestimated. What it had here was a system of living semiconductors—extremely fine membranes that transmit impulses along barely visible tubes and in one direction only: from the nerve to the muscle.

Our familiar semiconducting devices have, it turns out, very good predecessors. They are much smaller than the smallest transistors and are made out of practically nothing: nature made do with water and a minute dose of two or three salts. There you have the latest in technology with a background of some millions of years! Too bad nature doesn't patent her discoveries. They would surprise many an inventor. So what happens to the impulse?

It races down an open path to the myofibrils. The electric charge plunges into the electron habitat and excites the electrons to a new high energy level: the muscle contracts. The force of contraction is ordered by the central nervous system, which roughly, though rather precisely, determines how many muscle fibres are to be switched in to make the shoulder itch, the hand strike, the....

The nerve is a live and temperamental thing. Thousands of signals are always on the go racing along at 300 some kilometres an hour. They cover the distance between brain and the most distant

muscle in a minute fraction of a second. Every impulse races—a messenger with important information. Out of this stream of signals the muscle instantaneously picks out the one addressed to it, decodes the signal and promptly executes the order from up above. The orders come in overwhelming numbers, but each one follows its specific channel, or nerve fibre.

It is no easy job to take care of all the subscribers of this multichannel network. Nerves have had to organize a sort of labour-protection system and a minimal period of rest—two or three thousandths of a second. Here is the way they do it: not one of them will transmit two signals one after the other. No matter what the urgency, it will not perform until the rest period is up. Something like the lunch hour in a village post-office: just wait. Luckily, there are thousands of millions of such post-offices so that if one doesn't respond, another somewhere will. That is how the signal finally gets to its destination.

Incidentally, there is some sense in a little waiting. While the impulse is hanging around at the threshold, the nerve restores its electrical conductivity, which, strange as it may seem, is very small. This many-stranded cable is a very poor conductor. How it actually gets such important information to the muscles in time is simply amazing. Signals peter out in the nerve within half a centimetre, yet information is occasionally delivered to distances over half a metre or more. And it is never late. This couldn't be another technological "breakthrough", could it?

Yes, if one wants to consider a relay-amplifier as radio-technology news. There are lots of these relay substations in the nerve fibre. Each one picks up an impulse, amplifies it, and transmits it to the next substation. Thus a signal is kept from fading out. All this is done on a mutual-benefit basis. An impulse stimulates a small portion of a nerve; this excited portion then supplies the impulse with energy, pushing it on. On the next section, the performance is repeated and so on until the destination is reached. Like fire racing down a Bickford fuse. When it reaches its destination there is an explosion—the muscle electrons begin to release quanta of energy.

This, of course, is only a rough outline of nerve mechanics. Actually, nerve conduction is a much more complicated process than our conception of the most intricate system of electrical communication. The nerve and the muscle have not yet revealed their electro-chemistry, which is where the chief secrets lie. Surely the technical wonders of our age fall short of this greatest creation of nature—the human organism.

THE BATTLEFIELD OF IMMUNITY

Yours and Mine

The first thing I'd like to know is whether one can infect a microbe. Say, with the common cold. Just have him sneeze. Let him be hostile to man, his enemy. I would be happier about hostility like that more than about some kinds of love. I am really fed up with the old formula that "microbes are man's enemies". How about changing their places: man is the enemy of microbes. Man does the attacking and they are on the defensive. Then, maybe, microbes will strive to avoid humans; perhaps they will even get to be misanthropes altogether. As it is, however, bacilli are unaware of their bitter fate and go right on deep into the body, which protects itself with a whole system of barrier mechanisms that go by the magic term immunity.

This word brings to mind the name of Mechnikov and the inevitable phagocyte. Mechnikov was definitely right: this blood corpuscle is an excellent microbe catcher. But alone, the phagocyte cannot do the job. Neither can the millions upon millions of his brothers. There are still too many microbes. Ordinarily they deal a massive blow and proliferate at such a rate that even the voracious blood corpuscles are not a match for them.

While a phagocyte is eating up one of the enemies, a host of descendants are already in the field.

No, microbe cannibalism is not the best self-defense system. What we need is fighters that are tougher and come in larger numbers than phagocytes.

Obviously, man has such helpers, otherwise he wouldn't be winning out so often against bacilli. Who are they, these new guardsmen of health?

First of all, this is something more complicated than a simple fight with microbes. Good as the phagocytes are (they do what is expected of them), there are cells with jobs far more important and with much greater powers. They not only repulse onslaughts of outside enemies, but keep strict control over the internal life of all the body tissues. They are charged with the task of maintaining a constant protein composition. This in itself is no less honourable and responsible than hunting microbes.

The human organism does not allow for the slightest alteration in the set of its proteins. They come once and for all, for a lifetime. If a foreign protein puts in an appearance, the checking cells spot it instantly. They have a delicate sense of what is theirs and what is not. They track down the unwanted guest on the slightest evidence, then they throw up a sanitary cordon and destroy it.

Some memory they must have to be able to discriminate among the thousands of their own proteins and almost instantaneously spot an outsider. One might think they had a special password containing the protein code of all the tissues.

This seems to be the case. These watchmen of intratissue order remember all the proteins of the human organism and refuse to accept any outsiders.

Nature has certainly worked out an excellent filter. Without it, the organism would very soon get cluttered up. Thanks must go to our old friend the lymphocyte. Close relative of the phagocyte, it defends the organism with all its strength and with knightly self-sacrifice.

True, this has not always been in the best interests of the individual. Occasionally, sound foreign tissue is more desirable than one's own but diseased tissue. The body demands an exchange like this, but the lymphocyte is blind and impartial. It just as stubbornly rejects bacilli, viruses as transplanted skin or kidney or any other organ or tissue. So long as the protein password is different, it rejects the newcomer, no matter what. That is how nature's mechanism of protection overplays its role and acts to the detriment of the body.

Immunity is a powerful but double-edged sword. One has to be particularly cautious. Who knows what surprises it might not have in store. It is very possible that it has to protect the tissues not only against foreign proteins but also—*horribile dictu*—from malignant regeneration. We know there is some kind of tissue immunity to cancer: some people succumb, others, fortunately, don't. Cancer is ready, always ready, but some tissues refuse to give in.

Who helps them?

There is apparently a mechanism within the body that keeps watch over normal cell development. Any deviation is immediately repaired, the weed is rooted up. And life goes on again normally. The trouble starts if this protective device fails to operate in time. Then the tissue, like a speeding train that takes the wrong track, plunges on to disaster. This is all supposition, don't forget, but if it is confirmed, the lymphocyte should have a gold monument erected with the inscription "From grateful humanity". Meanwhile, we will confine ourselves to praise for this selfless struggle with the enemies of the body.

We might conclude our glorification of lymphocytes and also this chapter if it weren't for one important circumstance. Our heroes are rather sluggish fellows, wandering as they do about the body alone and as slow as night watchmen. Out against them are vibrios, spirochetes, Koch's bacilli, and all kinds of other microbial evildoers. How do the lymphocytes score their victories, what weapon have they against such terrible enemies?

Protein against protein. Home-town protein fights outsider. Nature pits them one against the other in a mortal struggle. The lymphocyte wins out in a fierce battle. At the height of the conflict, it turns out a thousand specialized protein molecules every second. The weapon is gamma globulin.

The lymphocyte uses it like an experienced sharpshooter. It aims each molecule at a strictly definite target—bacterium, virus, foreign pro-

tein. This bullet homes onto the intruder picking it out of the hosts of undesirables. They may be many, but the body is prepared.

100,000,000,000,000,000, or in shorthand, 10^{17} molecules of globulin are sent into the fray against invading proteins by every cubic centimetre of blood. That is the standing army, and there can be no question of discipline, unity, or self-sacrifice. At the first suspicious signal, lymphocytes are on the firing line. And they don't back down until the last microbe is wiped out.

Proteins are not the only things that cause stiff resistance. Artificially synthesized substances, like aniline, which never came up against lymphocytes because it is not produced in nature, are repelled by the militant corpuscles when introduced into the bloodstream. Lymphocytes intensely dislike anything foreign. They would probably even go against a microscopic ranger from Mars.

What is the secret of this astounding feeling of the white corpuscles of the blood? Why are they indifferent to their own proteins but are intolerable to intruders, and how do their bullets seek out their targets, and how is it, finally, that they are able to tell their own from outsiders?

This is probably just the time to discuss the whimsical protecting protein, gamma globulin.

The Tribulations of Insulin

The lymphocyte fires at microbes with molecules specially tailored to fit the victim. No matter what encounters there are en route, it is only the

victim that is hit. The whole trick lies in the production technology of these aimed bullets.

A molecule of gamma globulin gets attached only to the protein that could be used as a mould for forming it. It has to be a perfect fit, otherwise no force can link them up. But this never happens. The body's tailor shop invariably turns out clothes to order so that the fit is exact.

The gamma globulin grips the microbe and holds it hand and foot. From then on it is impotent and soon withers away. The lymphocyte triumphantly takes over.

Incidentally, not all the victories of this fighter are scored in favour of the individual. As we have already mentioned, the lymphocyte is absolutely intolerable in its attitude towards the transplantation of organs. The fault is a grave one, often fatal, and unfortunately not the only one.

Lymphocytes are a stumbling block in the treatment of diabetics. No matter how much insulin is injected into the patient, this stubborn corpuscle produces the same quantity of anti-insulin proteins, which promptly fling themselves into the fight against the drug, immobilize it and then eliminate it from the body like any old parasite or bacillus.

Luckily, not every insulin produces such a fierce fighting spirit in the lymphocytes. A preparation made from the pancreas of a hog remains long enough in the blood of the patient, and diabetic patients have been using it for years with no adverse effects. Quite the contrary, beef insulin comes up against merciless resistance on the part

of the corpuscle. Where do these bull-fighting traits come from?

This time, it appears, scientists really took the bull by the horns. They know the actual chemical structure of beef insulin. And the insulin of sheep and pigs, as well. To find the source of the trouble, one had only to compare the chains of amino acids in these hormones and detect any variations.

The difference turned out to be extremely small. Of the fifty-one amino acids that make up insulin, the beef hormone differs from the hog hormone in only three—all the rest coincide. There were no longer any doubts. These three spelled the failure of beef insulin. They, and only they, were the ones that signalled to the lymphocyte, which responds to the "spot" on the "body" of insulin and begins generating an antibody—a special gamma globulin.

Thus, for the first time, biologists delving in the debris of a protein molecule got their hands on a tiny piece that trains the organism to distinguish its own material from foreign bodies. One fact like this was worth oodles of conjectures. For scientists now had in their hands—and not only in their minds—a peculiar chemical key that triggers one of the immunity mechanisms of the human organism. It justly received the name "active centre".

Insulin is not the only protein that has such a centre. Similar centres will undoubtedly, in time, be discovered for other more complex proteins as well. The search is worth it because the centre contains important information. Coded into the

chain of amino acids, it is constantly signalling to the organism: "Attention, we are foreign, defend yourself!" Besides the signal, it reports on the forms that the defense antibodies must take. The "key" takes an active part in manufacturing the "lock". No one has seen how it's done and so there are more than enough hypotheses and conjectures. But certain facts make it clear that an antibody is always produced directly via the active centre. The "key" makes a sort of dent in it, which is biologically meaningful.

On this raw antibody fashioned out of amino acids, the microbe leaves its trace, its fingerprint, as it were, making it readily identifiable for destruction. Nature has its own trap ready: "If you want to live at somebody else's expense, go ahead, but once you enter the human body, then forge the weapon that will destroy you." Which it does. The jungle laws of immunity take over.

Microbes find it hard going when they encounter antibodies. But where do antibodies get their strength? Proteins have the same amino acids as viruses and bacilli. And the molecular weights are about the same, just like boxers in a ring.

How is it that one wins and the other loses, after all?

The Profile of a Molecule

At first glance, gamma globulin operates rather simply: veni, vidi, vici. How it comes and how it sees, I have discussed. But about gaining victory, the third element, I find it hard to begin.

The fact of victory is all well and good. But how it was done and what initiated the fight is something different. The point is that anti-microbial antibodies do not differ at all from ordinary globulins. The fighter-proteins and the microbe-indifferent proteins are composed of exactly the same amino acids.

Experiments were conducted, delicate analyses performed, but nothing showed the militant globulin to be any superior, chemically, to the peaceful one. They were protein brothers definitely.

The closest relatives have no small number of special traits, yet here a quarter of a century failed to detect a single significant one. What is more, it transpired that antibodies have no features of their own. They attack a variety of viruses and microbes but themselves seem all alike. At any rate, no one has yet found any perceptible differences among them. Like soldiers at a distance, they are hardly distinguishable. Perhaps it might be possible to make a mental approach, examine them conceptually.

One of the most interesting surmises has been expressed by the well-known scientist Linus Pauling. He reasoned from the reverse. Certain globulins are active, arrogant, others are inert, while the chemical difference between them is not noticeable. Which means that there is some other factor. What is it? Most likely the outward appearance of the protein, its physical aspect. A chain of amino acids of the "peaceful" globulin coils up according to a certain specified plan, then suddenly gets excited and acquires fighter-like

properties to become an antibody. What imparted this fighting form? The microbe itself of course. Once in the organism, it began to stamp antibodies, twisting globulins after its own image. Simple? Logical? At any rate, it's hard to resist the temptation.

Unfortunately, it is also just as difficult to find proof. The point is that nobody has ever seen an antibody face to face. No one knows how the amino-acid chains are coiled. Therefore, it is harder to prove this hypothesis than to state it. However, occasionally, gamma globulins themselves speak in favour of Pauling's surmise. And not in the laboratory, but in actual practice helping sick children fight off microbes. Gained from the serum of an immunized horse or sheep, they serve as excellent support to the antibodies proper of the child.

These newly acquired gamma globulins are thrown into the fray straight from the march; they reorganize their anti-microbial properties on the go. This rapid reorientation may be due, to some extent, to the mobility of their structure, a peculiar and unusual biological plasticity of each molecule of gamma globulin. After every rebound from the enemy, it turns against the latter. Whether that is so or not is not known, but if Pauling is right, then gamma globulin is truly a wonder protein.

A delicate and amazingly refined mechanism protects humans from hosts of dangerous ailments, yet by itself it is defenseless. Ionizing radiation can do gross damage to this delicate structure of

nature. The ruinous ray penetrates the organism and does irreparable damage to its most important functions, including the production of antibodies. Every nuclear explosion, no matter how far away, generates a heavy echo in the most sensitive tissues of the body—the blood-forming and lymphoid tissues. That is why one of the world's most distinguished biologists, Nobel Prize Winner Linus Pauling is among the best representatives of our century tirelessly struggling against this terrible threat to the health of millions of human beings.

Today proteins are at the heart of biology. With the excitement of real pathfinders, scientists are studying the mysterious maze of amino-acid chains. They are penetrating deeper and deeper into the protein molecule along tortuous pathways. They hope to find markings that will help resolve one more enigma of the human body—immunity.

Incidentally, antibodies have already opened up a number of important peculiarities. They too, it appears, have active centres. The difference, however, is that these energetic groups of amino acids are designed for entirely different work—to capture and immobilize the enemy.

Each gamma globulin that attacks a bacterium apparently has a very tough section, something in the nature of a chemical "hook". Although it is only a few hundredths of a molecule in size, the defense properties presumably depend mainly

on it. Microbes bite on this "hook". No wonder biologists have long been interested in how it operates.

It is no easy job, however, to locate the active centre somewhere in a long chain of amino acids. It was decided to split the molecule—the antibody—with a special enzyme and search for the lost centre in each half. Luckily, during division it remains intact in one of the fragments, becoming larger in a relative sense. That makes it easier to locate than in a whole molecule. The likely area is narrowed down.

True, this split in halves was not enough. Half a molecule is still too large an object to be sure of finding this tiny section that attaches itself to the microbe. So the dividing went on.

The enzyme papain, which is obtained from the exotic papaw tree, split the antibody into three parts. This was something: two of the three fragments had active centres, the third was empty, but not useless. It formed a bridge or body between them with two grasping arms, each having a hook.

To the chemist, this would be a bivalent structure. Which is really so, for an antibody holds at bay two enemies at once. Active centres operate in pairs and in unison, energetically and without error: each hook gets its piece.

Perhaps "gets" is not the right word. It may be that the microbe heads towards it all by itself, attracted in some strange way; say, by the attraction of unlike charges or via the reaction of related chemical groups. As yet we do not know

for sure. This fragment of gamma globulin has revealed the anatomy of antibodies only in general terms. Rather like an isolated bone found in archeological excavations enables the scientist to conjure up a picture of some extinct animal.

But the biochemist is never satisfied with a general picture, he must know the very minutest details of the antibody, the tiny screws and gears that relate of the hidden mechanisms of immunity. To search them out, we must go deeper and deeper into the interior of the protein molecule.

Unfortunately, this job does not get easier as we go along. The farther we get into protein, the more riddles we encounter. The very molecule of gamma globulin itself is a nut of rare hardness. It cuts into three pieces but no farther. Its fragments are reinforced concrete; not a single enzyme can break through, even the fiery southerner papain gave up. Scientists had already reconciled themselves to the limitations of papain when a new angle was found.

True, a little help was needed to soften up the fragment of the protein molecule and make it more amenable to "reason". The chain of amino acids here is in a tight coil wound like on a spool, turn after turn. The enzyme simply couldn't get its clutches into it.

Now in the presence of urea, papain boldly tears the amino-acid chain into pieces. It bites out links and converts the rest into free amino acids. Then biochemists sort the pieces out, count them up and determine the site of each amino acid in the molecule of gamma globulin. The mute

map of the antibody now displays fresh names, and the outlines of the protein put on real chemical flesh.

Medicine of the Future

Urea uncoiled the amino-acid ball and helped the enzyme to break each of the three fragments of gamma globulin into three parts. Now we can peer into 1/9 of a protein molecule and make a real search for active centres. The point is that in a fragment of that size there is almost ten times more material (proportionately) than in a whole molecule. Hence, it is easier to get our hands on these mysterious hooks.

Physicists breaking up atoms will perhaps smile: one third of a molecule, one-ninth part—childish. We deal with neutrons and photons! Well, the biologist works with living cells, which cyclotrons don't handle. To be quite frank about the whole matter, this stubborn and temperamental little cell promises to be a greater friend than all the split atoms taken together.

Not only promises to be, but has become. When I wrote about the misfortunes of beef insulin, I didn't want to mention any other protein tricks. But now I'll have to in order to show how biologists double-trick them.

Serums occupy a place of honour in the medical world, and have for a long time. They deserve it, for they have saved literally millions of lives. These ready-made antibodies fight microbes no worse than those which the organism itself pro-

duces and it is better to introduce them than to wait until the patient sets up his own production of anti-microbial weapons. But the trouble is that these life-saving serum proteins are foreign. And so after a while the body starts turning out antibodies against them.

Quite some plight we have got into: antibodies fighting antibodies, while the microbes rejoice and multiply. The trouble is not solely with the microbes. The body itself occasionally responds to repeated injections of serum with severe shock. That is why doctors are very cautious about using it. It can start out curing and end up fatally.

This is certainly a blind alley. The drug that is supposed to heal does more harm than good. Is there a way out?

There is: the splitting of serum antibodies. To put it simply, they have to be thoroughly cleaned of amino-acid excess.

Indeed, the entourage of amino acids in an active centre is far too great. Since the microbe is caught by a tiny hook, why have a huge unwieldy fishing pole? If we cut it down and remove the extra protein, then the active centre entering the blood of a patient will not generate antibodies but will perform its direct duty of immobilizing the microbe. In this case the serum disease will not develop.

A light-weight refined preparation like this is the age-old dream of infectionists. Too bad that it constantly came up against rock-hard globulins. But its turn seems to have come at last—wide use is already being made of the serum

Diaferm-3 prepared at the Gamaleya Institute of Epidemiology and Microbiology. This drug contains nearly half as much protein as ordinarily and for this reason is not so dangerous. Still it is not yet completely devoid of pathological properties.

Even a third of a molecule of gamma globulin does not lose its capability of causing serum disease. But smaller particles are practically harmless.

If so, then why not get them to the clinics as fast as possible?

I too wanted to see the curative power of these marvellous drugs. But, it turns out, biologists still have a big job ahead of them. They've got to learn to break the protein up into a large number of lobes and select the ones that contain active centres. Say we succeed in dividing a molecule into ten or fifteen particles, and only two of them have "hooks" (antibodies, as you recall, are bivalent). Then these two working particles will be left in the serum and the others will be removed as harmful entities.

A serum saturated with active centres, a sort of biochemical concentrate, will hit microbes harder than some antibiotics, while the dosage will be a fraction of what it is now. Bacilli will not be able to get used to a drug like that, and it will be harmless for the patient—which is not always the case with many powders and pills. What is more, the doctor will be pleased by the exact measure and specific orientation. A real medicine of the future.

For the present, diphtheria, the measles, polio, tetanus, gaseous gangrene and many other infectious diseases are treated with gamma globulins extracted from the serums of immunized animals. Failures are rare but they do occur. The doctor is not always sure that the antibodies he has injected into the patient will be able to tame the microbes there. He frequently gropes in the dark, hitting out haphazardly, not waiting until the bacilli win. The physician will be glad to receive from immuno-chemists pure and concentrated drugs oriented against specific disease agents.

But serums are only the beginning. Beef insulin can be used in this way against attacks of antibodies. Out of the insulin molecule they take only the active group and inject it into a diabetic. Then they let a lymphocyte try to figure out which protein is foreign and which is not. In time, biologists will clean up hormones and protein preparations on a grand scale. All superfluous items will be disposed of and the organism will receive a precise dose of first-rate protein.

That is the conception. The execution? You must have guessed already. Yes, it depends largely on the scientists breaking up protein molecules and deciphering the structures of antibodies in search of active centres—in a word, it depends on the successful resolution of the problems we have just got acquainted with.

THE CODE OF LIFE

Every cell has a farm, a small one, but a profitable one. The farm constantly supplies it with valuable produce like proteins and nucleic acids. The owner is no spendthrift and covers all expenses and even puts away a bit. The organism draws on these reserves, which are continuously being replenished to keep important physiological processes going.

The cell grows and needs protein. The cell works, gets thin and again needs protein. Finally, the cell has to multiply, which again means more protein. All these expenses are readily covered by the cell's nicely integrated small-scale farming services.

A remarkable production unit indeed! No wonder scientists have been trying to probe the production secrets of this outfit for over three centuries. But this little piece of living tissue is obviously not over eager to give them up. Biologists have been studying its innards for so long and numberless involved suppositions have been expressed, yet the cell remains full of unusually intricate and thrilling riddles.

The cell is a very special entity. And rightly it should be, for the chief architect was nature, which builds to perfection. Why shouldn't it,

what with its practically boundless building experience and ever so much time? This most likely is the reason why a drop of life pulsating in the eyepiece of our microscope is still staggering researchers with its delicate and amazingly integrated mechanism.

To probe these mysterious workings, scientists have thought up many interesting instruments. Probably the biggest discoveries have been made with the electron microscope. With its enormous magnifying power of tens of thousands of times, it has revealed to investigators such a fairy-land that we again experience the thrills that Leeuwenhoek felt. We can understand the joy and distress of the inquisitive Dutch naturalist, who three centuries ago looked into this unknown living world. That is how a technical discovery suddenly brings distant times to mind.

The electron microscope has enabled us to look into the living cell deeper than biologists had ever dreamed of.

Inside the Cell

The cell was now examined for the first time with the help of a stream of racing electrons. Things showed up that ordinary light rays had failed to reveal.

The electron demonstrated the cell to have a membranous structure. Inside is a whole network of fine partitions—long tortuous chains of protein molecules and fatty substances called lipids. They divide up the body of the cell into a host

of interconnected chambers and compartments. Sometimes stretched out in the form of narrow bags, or coiled up into whimsical wineskins, these membrane-like partitions form around the cell nucleus a complicated and, unfortunately, little understood labyrinth. One thing that we do already understand about it is that protein is stored here. All the bags and wineskins are packed full of proteins. The question is: How did they get there?

The cell makes no secret about this. We all know that it makes do without outside help. Hard work and thrift are the source of its prosperity. It is constantly thinking about its food store and reserves. So it set up the production of proteins out of local materials—amino acids, of which there are endless supplies all about, since the blood is constantly bringing in more and more.

The main thing is to know how to make use of the materials. The construction of huge multi-storey molecules of protein is a painstaking job. The point is that there is a definite tenant on each floor—one of those twenty amino acids which, in a multiplicity of combinations, like letters forming words, go to make up the numberless multitude of proteins.

An error here is worse than a spelling mistake—it is simply dangerous. The slightest deviation in a protein molecule will immediately distort its whole inner structure, and do real chemical damage. The result will be an invalid protein that no one needs or can use.

But amino acids have nothing to do with such

details. They can unwittingly link up in the wrong way with their cell neighbours. To keep traffic straight, a strict code of conduct had to be instituted. Here is the way things are handled. Protein molecules are put together by assembly-line techniques where each unit performs a specific operation.

Here the protein is put together part by part, in accord with an established pattern—deoxyribonucleic acid, or DNA for short. This is the principal and almost invariable pattern used to manufacture proteins.

No wonder this compound is extremely stable. DNA is the guardian of the "family" features of the protein, of all its inimitable structural peculiarities, the hereditary properties of the living cell. They are encoded in the spiral-like molecule of this complex substance by some mysterious cipher.

Nature exhibited amazing ingenuity here. It coiled up the helical molecule so economically that it easily accommodates the entire code of the endless chain of amino acids which go to form proteins. DNA is like a safe with the family jewels. The whole trick is that the jewels are passed on from generation to generation and no one is able to see them: the safe is tightly closed. It has been much more difficult to find the key to life than to decipher the ancient writings of the Aztecs.

It was only just recently that the mysterious alphabet of living nature used to write down one's facial features, the colour of the eyes, the potenti-

alities of a great musician or a brilliant chess player—in a word, the detailed outline of a future human being, right down to the fanciful whorls on his finger—the entire magical and inimitable language of life gradually began to open up in rigorous chemical formulas.

The great and the simple lay side by side. The whole vast complexity of life fitted into a three-letter code by which DNA gives orders that handle protein manufacture. Four substances are used. Four letters—four substances—alternate in the structure of DNA. Each one of them is a signal to the construction site, where a protein molecule is being fashioned out of amino acids.

We now have to find out how these signals get all the way across the cell to the construction site and what their destination is. First let us go back for a moment to the cell nucleus which hides DNA.

The secluded life that DNA leads is not a whim of nature. There is great biological meaning in it. Only a substance with unswerving chemical stability is able to serve as a model for numberless generations of proteins that supplant each other over the span of a human lifetime, and to convey always the very same set of "family" features. The DNA hidden in the nucleus is distinguished by a persistent striving towards constancy. It is alone here, but is nearly invulnerable.

It is precisely this advantage that probably nominated DNA to such an important post among the multitude of chemical substances that inhabit the cell. Nature seemed to appreciate the con-

stancy of DNA and entrusted it with carrying hereditary characters from cell to cell, from human being to human being—in a word, safeguarding and determining the fate of future generations.

True, it is no easy job to serve as a model all the time. Then there is the responsibility. If DNA is altered in any way, say by X-rays or radioactive radiations, the protein copies it turns out blindly repeat the newly acquired feature. But this is only an unpleasant exception; for the most part, DNA performs its duties with amazing accuracy. What is more, it has skilful assistants of the same type of nucleic acids. They are called ribonucleic acid, or RNA, for short. Even in the manufacture of proteins, one needs managers and also ordinary workers.

Protein on the Production Line

DNA manages the whole works without leaving its "office", the nucleus. This is not bureaucracy at the molecular level but simply well-organized labour. The manager need not run about the factory if he has experienced assistants on the job.

DNA sends to the assembly department of the cell its representative RNA, which immediately gets to work turning out proteins composed of amino acids. It's done not any which way, but according to a strict programme. Before leaving the nucleus for good, RNA learns from DNA all the tricks of construction and the entire chemical code, imbibing the unique peculiarity of future

proteins and cells. Like an engineer working from blueprints, RNA takes from the cell nucleus a detailed plan for protein construction.

Everything is very simple: RNA lines up right in the repository of the genetic code. The chief cues are those four substances that DNA uses to signal with, like flags. A definite component moves up to each "flag" and joins into a nice new molecule of RNA. That is how DNA, using chemical signals, transfers its features to RNA, which, being a mobile substance, takes them outside the nucleus to the protein assembly department.

The signal, which contains all the blueprints, races over to the construction site.

RNA is in a hurry to convey the information contained in its structure. Now we shall leave it for quite some time. Remember it well, for it deserves attention: this chemical messenger is now carrying the most important message in the world—the protein code.

There is nothing exceptional in this molecular hero: the same oxygen, hydrogen and nitrogen, yet it contains the greatest wonder of all, the mystery of the reproduction of life. It is always in a hurry. Like a matrix, it is capable of "printing" colossal quantities of protein molecules, all absolutely exact replicas of the original.

True, mistakes occasionally occur, but even so nature makes use of them. Nature makes a careful study of the slightest defects in DNA operation over a number of generations, the aim being to hold onto any minute change for the better.

This peculiar kind of natural selection among newly produced molecules apparently plays no small role in the development of the living world.

Nature has probably never found more fitting uses of its own defects. It has made the imperfections of DNA serve in the refinement of organisms. There is truly infinite optimism in the saying: "Every cloud has a silver lining". Nature definitely is the greatest lover of life on earth. Let us follow its example.

Unfortunately, it is no easy job to penetrate into this laboratory and ferret out nature's trade secrets, which are bound up tightly in the protein molecule. The task confronting biologists is to unwind this ball of living secrets. Scientists have already taken the first steps. The door is now open into the assembly shop of the cell where protein is synthesized.

Biochemists have known that RNA is boss here. But how it performs its duties, who are the helpers and where is the work done—were all question marks. The inner life of the cell has become the central biological problem.

Electron microscopes and sensitive oscillographs focused onto the cell trying to penetrate its fine structures and discover some minute feature, while penetrating X-rays kept snapping it in all poses and from every imaginable angle. Then biophysicists got the idea of feeding the cell with radioactive food—tagged amino acids—and following their transformations from deep inside. Then biochemists got hold of the protein and broke it down to its ultimate constituents.

After that they started putting it back together again. It was a virtual jigsaw puzzle, where hosts of minute fragments were joined to make a whole molecule.

It turned out to be much easier to break up protein than to collect the pieces into a normal chain again. The trouble is that every particle of protein (amino acid) in this chain has a very specific place, a permanent site. If the address is confused, a different protein results, and there are thousands of millions of addresses in this molecular madhouse. Just try and put something together.

And they tried. Fragments of protein were used to build an elegant structure—the insulin molecule. The building had gone on for ten years with all kinds of combinations under test. At least scientists now have a good idea of the chemical structure of this hormone, its address book, one might say.

Insulin was the first success and it whetted the investigating appetite of biochemists for hormones and enzymes. And for good reason, too, because these active proteins play a very important part in the organism, regulating all life activities.

Since then, fresh names are all the time appearing of new proteins being deciphered. Included are a large number of hormones of the pituitary gland, the most important of which is the adrenocorticotropic hormone—ACTH, the growth hormones and certain others.

Of course, the resolution of protein riddles is not an aim in itself. Though it is intriguing to

unravel a new mystery of nature, scientists derive greater satisfaction from bringing people tangible results, for the soul of science is in the practical applications of its discoveries. Here the excitement is all the greater because biochemists are more and more dealing with the very profoundest of life processes.

And no wonder, for not a single body reaction takes place without enzymes, while hormones are total masters of metabolism. Some of them are invested with great power, controlling other hormones and directing and regulating the life of the whole body. Some of these commanding hormones direct the performance of several glands of internal secretion at once.

These all-powerful substances hold key positions in the crowded management of the human organism. Wouldn't it be nice to have control over these overseers!

To do this, we must first figure out the chemical skeleton of the active protein. Scientists hope to find the primal cause of the extraordinary biological force of hormones and enzymes in the minute features of protein structure, in the fine anatomy of the protein molecule (anatomy at the molecular level!).

A short time ago biochemists made a breakthrough in synthesizing two pituitary hormones (vasopressin and oxytocin) out of ordinary natural substances. The artificial hormones did not differ from their natural prototypes either in the chemical formula or in physiological action. They behaved so naturally that the body did not notice

the substitution. When introduced into the blood of an animal, synthesized oxytocin invariably caused uterine muscle to contract, and vasopressin rapidly constricted vessels.

Thus, a chemical experiment opened up another secret laboratory of the living organism—the hormonal laboratory. Biochemists passed from anatomical studies of protein molecules to the actual constructing of them.

Here, scientists were in for yet other and more remarkable surprises. They found some technical faults in the structure of certain protein molecules and took it upon themselves to correct the faults of nature's laboratory. This is how it went.

Researchers analyzed the structure of ACTH and found this hormone to consist of thirty-one amino acids. But when they got to returning each one of the acids to its respective site and tested the action of this unfinished hormone on an animal, it was found that biological activity requires only twenty-four amino acids. Seven acids had turned out to be empties, just ballast. In this elegant experiment, biochemists caught nature on the extravagant side.

The history of ACTH was a start in an overall purge of hormones, serum proteins and other drugs. Apparently, we have not long to wait before the insulin molecule is relieved of its dangerous surplus....

But human beings do not live by hormones alone. A word is in order about enzymes. These are very peculiar substances endowed with enormous energy, which they strive to impart to amino

acids, and with a peculiar habit of staying by themselves. Enzymes never form firm bonds with any other substances. They perform their duties and fall away. The initiated reaction then proceeds by itself.

An enzyme is not only a sort of primer for chemical reactions, but also a weapon of the living cell. A powerful and sure-hitting weapon that has great control over amino acids, which the cell uses as building blocks when laying the foundation of its house.

At this construction site, enzymes act as foremen that keep up discipline in the cell. Without them there would be chaos, for there are oodles of molecules racing about like mad. Yet this entire molecular ant-hill is kept under strict control by enzymes—the regulators of vitally important processes. There are thousands in every cell, each performing specific duties.

Enzymes function in different ways, sometimes hardly at all noticeable, at other times aggressively and decisively interfering in the complex interrelations of the cell community. Some they bring together, others they separate. Not a single life process occurs without these exceptionally hardworking biochemical intermediaries.

The cherished aim of every enzyme is to seek out the right amino acid among a host of others; the perfect fit, you might say. And then to give up to this acid all its vigour, its tremendous energy, and to switch it into the active life of the cell.

No easy task, but very noble. The enzyme excites an amino acid to activity and thus sets it

on the proper performance path. Just a moment before, a substance with no particular profession—now suddenly an active builder of protein. That is its true calling.

But the enzyme only gave it a push; something has to carry it to the site where proteins are assembled. Amino acids in the cell are like newcomers in an unknown city—which way to turn? Meanwhile the organism is constantly demanding proteins.

Take a taxi, our familiar RNA vehicle. But this time it is not the RNA matrix that served as a pattern for turning out proteins. It is a mobile RNA, a kind of intracellular runabout.

It is called messenger RNA and delivers amino acids to addresses recorded in the RNA matrix. Real complexity: a single substance doing two jobs at once. Earlier I mentioned the cell maintaining a strict division of labour, but obviously there is more to it than that.

The messenger molecule performs its duties with exactitude, taking only one permanent passenger at a time—one of the many amino acids hurrying to build up proteins. It delivers the goods, dumps them and sets off again. There is never any mistake, since both driver and goods are linked in a chemical bond. That is why the messenger RNA readily and precisely picks up only its own amino acid in the terrible molecular mêlée. One out of twenty varieties, you remember. What about the others?

This time nature was generous and allowed each amino acid a private RNA chauffeur. Which means

that there must be at least twenty RNA messengers with their vehicles. A whole auto pool!

Just try to picture this intricate pulsating microscopic blob of life in which molecular trainloads of enzymes, salts, amino acids and so forth are constantly—day and night—racing along a maze of pathways following ultraprecise timetables.

The messenger RNA picks up its molecule of amino acid and delivers it right to the assembly shop of the cell. From now on is familiar ground. Here are the very same membranes that partition the cell lengthwise and crosswise.

On the surface of the membranes is the protein conveyor. Here molecules are assembled, multitudes of RNA matrices that arrive straight from the nucleus are at work. RNA taxicabs are constantly arriving and dumping off amino acids.

Here is where the most amazing things occur. Each taxi unerringly seeks out a specific and constant site in the long RNA matrix, then dumps the amino acid into the proper cell of the protein die, and is already on the return trip.

But how do nucleic acids recognize each other at a distance? Do they have a sign language of their own?

This is how it's done. The link-up points with the twenty RNA messengers are coded in the chemical structure of the RNA matrix with the same three-letter code picked up in the nucleus from DNA. That's what the code is for: to see that RNA messengers arrange the amino acids in a very definite sequence.

Some system, isn't it?

DNA turns out twenty RNA taxis, which pick up the same number of predetermined passengers and deliver them to addresses indicated by the same DNA in a special matrix. And all this is done rhythmically with strict self-control and low energy consumption. Automation at its best! Yet it just couldn't be otherwise, for life without matrix replication and without nucleic "dies" is simply impossible, it would never have originated on our planet.

It might be that the world was created on the day that the first molecule of DNA or RNA generated a copy of itself. All living things then followed from this "progenitor" that took a long time to appear in the ooze of the primordial ocean.

Of course, it might be that life could have developed in quite another way, using other patterns and a different principle of production, but then it would have evolved forms and shapes drastically unlike our notions of living creatures. And then you and I would definitely not be here among the inhabitants of our dear Earth.

Fortunately, the structure of our molecular progenitors contained limitless potentialities for modelling the most stable and plastic compounds that have carried living beings through millions of years and all manner of change.

Life, earthly life, is a gem of nature.

Thus, with the aid of RNA matrices, activated and energy-rich amino acids are delivered to their proper sites where they line up in a long twisting sequence to form a protein.

This is the code contained in the DNA. It spec-

ifies the sequence of amino acids in the protein molecule and thus imparts to it a rigid structure. Amino acids in a protein molecule look like beads in a necklace. They form the peculiar chemical skeleton of the protein. The result is a wondrous structure of nature.

Now we have only to fill up our bags and wineskins with our ready-made goods.

The protein chain has come full circle, and so has our chain of reasoning about the ceaseless process of reproduction of living tissue.

Nature has amazed us time and again with engineering feats, but the protein conveyor is probably the greatest of all. This most intricate mechanism functions flawlessly. Even among its own productions, there is nothing so fine, so precise as the protein "die". Yet, occasionally it slips up terribly turning out huge quantities of protein that go into the building of cancer cells.

This is a real tragedy, where the mechanism that has been reproducing normal living tissue begins to destroy itself with the same adamant will. The conveyor of life turns out death-dealing goods. Why does this happen? Where is the fault? And, finally, who is responsible?

Who?

There are so many answers to this question that not a single one could be termed exhaustive. There is always a chasm between the likely conjecture and its proof. The only way to connect

them is by means of a bridge made up of demonstrable facts. Which are not so easy to get. "Heavy, rough and tangible", they have broken many a fair hypothesis, leaving in their wake fragments that assert their independence.

Hypotheses are delicate things, but among them are some that are fact-proof—those that are constructed on the solid and irrefutable findings of science. Let us look into one of these simple and very interesting explanations of the nature of cancer.

Soviet Lenin Prize Winner Nikolai Emanuel took a view of the mechanism of malignant growth from the chemist's standpoint. He advanced a bold analogy between malignant growth of tissue and a self-developing chemical reaction.

Cancer and an avalanche-like chemical process —where is the similarity? On the surface, there is none, but a closer look reveals what is called a free radical. A free radical is a minute fragment of a molecule. Emanuel believes that this radical is the cause of those extremely unpleasant transformations of sick cells.

As if tiring of loneliness, a fragment like this becomes tremendously active. Which is to be expected, for atoms by nature are collectivists, always striving to get together and form a strong community. The disengaged radical is no exception; it, too, energetically seeks a union. Free but uneasy, it rushes about the cell in the hope of getting into some closely knit group of atoms. This outsider is in a frenzy to get linked up with lost friends, it attacks any intracellular formation.

But that is only half the story. The cell has such a diversity of salts and other substances that it can easily accommodate the newcomer with a wide range of offers, but the radical wants more.

Bounding with energy, it attacks the most valuable thing of the cell—the nucleic acids and proteins. The radical distorts their molecules, which, as we know, play a very important role in the life of the cell.

Damaged by free radicals, RNA is no longer able to construct a sound protein. It can only turn out defective molecules, which go to make up enzymes and straightway disrupt the normal functions of the protein conveyor and the whole life of the cell.

And DNA, despite its high position, is adversely affected as well. It becomes twisted and disfigured and thus serves as a bad pattern for many generations of proteins. These brainless copyists turn out the exact reflections of its twisted physiognomy. Which means that the damaged cell will not only grow but will also reproduce monsters. The descendants are cripples from birth. And the worst thing is that the sick cells reproduce at a fantastic rate—in a geometric progression. Free radicals go berserk and attack the regulators of intracellular processes, which are termed natural inhibitors.

When these are damaged, the cell is without rudder or sail. The stricken and uncontrollable tissue begins to proliferate at a rapid rate. That is cancer.

Such is the description that Emanuel gives for the chain of events that lead to disaster. Now where do these culprits, the free radicals, come from? And how do they get into the body?

That is precisely the point: they don't come in from without, the cell itself produces them. But what instigates it to such rash action? It wouldn't commit suicide on its own, would it? No, and we do know the true cause.

Free radicals are formed in cells due to penetrating radiation, ultraviolet irradiation, and to certain carcinogenic substances—all of which are known to cause malignant regeneration of healthy tissue. Scientists have long since been aware of the fact that certain injurious effects that give rise to cancer flood tissues with free radicals. This established fact to some extent supports Emanuel's hypothesis on the origin and development of tumours.

However, it is one thing to suspect and quite another to catch, and all the more so, eliminate. The presumed initiator of cellular uprisings plays a tricky game. It starts "civil war" but itself remains on the sidelines, for a free radical only incites tissue to destructive action, serving as a sort of priming agent of this pernicious process. Its energy contribution to this racket is so small that it is still able to engage the next victim—an inhibitor, RNA or DNA.

Are there any means of curbing the evil-doer?

An attractive feature of this latest hypothesis is that it points the way—not on paper but experimentally—to spotting and testing substances

that inhibit the terrible onslaught of malignant cells.

Here, the scientist is no longer alone. In this most important stage of the investigation, physico-chemist Emanuel went into a partnership with biologists. The problem was under study at the Institute of Chemical Physics of the U.S.S.R. Academy of Sciences, where a group of biochemists and histologists (specialists who study the fine structure of body tissues) are working under biologist Dr. Lana Lipchina. Experiments began.

The idea was to break the mentally constructed fateful chain of events in an acute laboratory experiment on animals. If successful, there would be added support for the hypothesis. The main thing was to find a weak link. Here is where the hypothesis played its decisive part.

The scientists reasoned as follows. Aggressive radicals attack tissue inhibitors, so let us add some artificial inhibitors. These potent but harmless substances combined with free radicals. If that is so, then they should tie up the overactive ruffians of the intracellular world in chemical bonds. But that is not all. The artificial inhibitors should, in the sick cell, suppress oxidation processes that supply with energy all protein-synthesis operations, which are especially intensive in the case of cancer.

A cancer tissue requires more building materials than a healthy tissue because of its higher growth rate. The protein assembly line works double-speed exhausting the energy supply of the organism. If it only knew to what end it was

labouring. The only way out is to deprive it of energy needed in protein synthesis. Without fuel, the assembly line gradually grinds to a halt and the death-dealing turncoat cells die off.

But before beginning the experiment, one more important circumstance had to be clarified: Will the artificial inhibitor adversely affect healthy tissue? A test was made on mice. Luckily, it distinguishes between good and evil, the mice did not suffer.

Now it was time to make a test of the anti-cancer properties of this choker of deleterious reactions. Again white mice appeared on the laboratory tables. All the little beasts taking part in the experiment were doomed: they were inoculated with leukemia, or cancer of the blood. This disease that floods the blood with leucocytes is merciless. Hosts of white cells oust all the red ones from the bloodstream and death ensues.

This time the doomed mice were divided into two equal groups: in one group, an artificial inhibitor (propyl gallate) was introduced at regular intervals; in the other (control) group, the leucocytes were left to run wild through the organism.

In all the treated mice, the number of death-dealing cells fell off perceptibly. In about two weeks, some of the mice had completely got rid of leukemia. Blood tests showed that they were healthy. The inhibitor had halted the growth of sick cells. It was a swift and energetic stop, accomplished much faster and more powerfully than ever before by other drugs. Even the mice that suc-

cumbed lived nearly twice as long as the controls, which of course all perished.

On the other hand, the cured mice had a surprise in store for the experimenters. An attempt was later made to inoculate the mice again with leukemia and it failed—those that recovered had acquired a stable immunity to this ailment. All attempts to break down resistance came to naught.

What is more, these mice turned out to be solicitous parents, passing on the newly obtained immunity to their offspring, which did not succumb either. A pleasant surprise indeed. The great experimenter Pavlov valued failures as much as success, for he knew that a discovery begins where an unsuccessful experiment ends.

Fresh facts brought new ideas, conjectures and, of course, experiments. It was found that an inhibitor suppresses enzymes depriving of fuel not only the cancer cell but the vehicles they ride on: sick tissue becomes poor in RNA molecules, which are precisely the ones that deliver amino acids to the protein assembly line of the cancerous cell. It is no accident that malignant tissue contains so much of this substance.

An artificial inhibitor upsets RNA synthesis and makes for transport difficulties in the sick cell. The acute deficiency of RNA interrupts the production of proteins scheduled for the tumour.

Cells of acinous cancer, leukemic tissues, acridine sarcoma and other malignant growths treated with inhibitors lost the ability to be grafted onto experimental animals. This was a definite achievement. But more was done.

Together with his young colleagues Lara Gorbacheva, Irina Sokolova and Galina Kukushkina, he demonstrated that an artificial inhibitor can put the protein factory of a cancer cell out of commission for a long time. This discovery makes us regard more carefully the search going on in Emanuel's laboratory.

However, in addition to tumour cells there is yet another causal agent of experimental cancer—viruses. How does the inhibitor react towards viral tumours?

Chickens gave the answer this time. Yes, since it was found that ordinary chickens are subject to viral sarcoma, experimenters have been investigating energetically to clarify the vagaries of malignant growth. For inhibitor tests, chicken sarcoma proved to be a very convenient model of the illness.

The left wing of a chicken was inoculated with a filtrate strained from a crushed tumour, while the right wing was inoculated with the same filtrate mixed with an artificial inhibitor. In this way, each fowl was experimental and control simultaneously. Time passed. Tumours, the size of an egg, developed on the left wing of every chicken, the right wings were unaffected. In only three cases out of thirty did the tumour develop on the right wing, and even then it was not more than pea-size.

The conclusion is rather evident, but researchers did not hurry, for it is known that viruses are largely independent in metabolism. Entering a cell, they retain the right to an independ-

ence of this intimate life-process. It is therefore difficult to say just yet whether the inhibitor suppresses protein synthesis in the affected tissue or directly in the pathogenic virus.

Such is the gradual advancement of science.

Disowning One's Own

All microbes are at swords' points. But if they could get together just once, they would all fulminate against their younger brothers, the viruses. And it would serve them right because these tiniest of all beings keep the world of microorganisms in a constant state of warfare. The troublemakers are divided: some strike out against human beings, others attack their own kind—microbes. In both cases the fighting is fierce.

With equal zeal, viruses attack body cells and disease bacilli. Their aim is to survive and to reproduce as many just as aggressive descendants as possible. And so they live by the law of "hit your own and others will be afraid". Which plays right into the hands of medicine. The domesticated virus of bacteria—bacteriophage—has been keeping "wild" microbes away from us for many years now. In attacking them, this unsuspecting ally of man is least of all concerned about the health of humans. All it wants to do is stay alive. But that is just the point, in the struggle to live, it kills, rather eats, the disease agent. What is more, a virus has a voracious appetite, and it likes to have children too.

In twenty-four minutes it hatches about 200 descendants in one cell. These, in turn, don't stay long in their incubator, but hasten in search of a new haven, where reproduction starts afresh. Minutes pass and again we have two hundred young viruses hurrying away to fresh quarters. All have the same aim: find living quarters and start all over again.

But the question is how to get into their desired dwelling, for we know that bacteria and cells are well protected with a tough membrane against unwanted callers, all the more so that the persistent guest is rather like a little doggy barking at an elephant.

But the minute virus is stout of heart and lashes out at the unwieldy bacterium with its own membrane, which serves as both a system of hooks and a battering ram. Once it has dug into a bacterial cell, the virus can call it a day, because in a few moments it will be snugly ensconced within. Not the whole of it, though; only a half.

A cell is not that hospitable. Certain things have to be left outside. These certain things are the protein membrane. Generally speaking, this membrane is no longer needed. The main thing is to get deep inside the cell, settle down and produce a new generation. That is the ultimate goal.

The membrane of a virus is filled with deoxyribonucleic acid (our familiar DNA which handles the reproduction of proteins). That is what the virus tries to push into the cell: here again the DNA is invested with extraordinary authority.

Without this substance, the virus is barren. In an electron microscope it is like an empty crumpled bag. There is no life for it without DNA and it soon perishes.

But once DNA gets inside a cell, the offspring is prolific. It becomes progenitor of a whole generation of viruses. It now has excellent quarters, good and abundant food and, what is most important, the cell offers protection against enzymes. Without a protein mantle, DNA is defenseless before their devastating attacks. Here it is nourished, warm and safe. There is nothing else to think about other than one's heirs.

True, to give birth to two hundred beings at once is no easy job. Each molecule of DNA, once inside a cell, has to generate a host of duplicate molecules and prepare protein clothing for them. A virus without a membrane is not a virus, and deprived of it, soon perishes. Therein lies its strength. How does a single molecule of viral DNA manage to conjure up so many nucleic acids and equip all new born with protein diapers?

Really mysterious. Yet DNA handles the business without a hitch, making use of a special mechanism. That will come later, but it would be interesting right now to find out what these strange entities are that continue the race with the aid of nonliving chemical compounds. Perhaps this is the dividing line between the living and the nonliving? In a word, just what is a virus?

NEWS FROM INSIDE THE CELL

Viruses have an unusual life history. A number of substantial victories over them had been scored before they were actually discovered.

The first acquaintance was in absentia, for neither Jenner nor Pasteur ever saw a virus and probably didn't even think that such a tiny fragment of life could exist. The microbe of all microbes. Yet they succeeded in making a vaccine against the terrible viral diseases of smallpox and hydrophobia (rabies).

This was a kind of prescience because even many years later, at the turn of the century, when Dmitri Ivanovsky discovered viruses, he was groping in the dark and never actually caught a glimpse of this remarkable world of infinitely small creatures. All Ivanovsky saw was beautiful patterns left behind on tobacco leaves by an unknown microbe. Like a master hunter, he recognized the beast from the tracks it left. Then he began pursuit.

This was reckless hunting. The invisible agent of the tobacco disease passed straight through the finest filters, went through pores in porcelain that caught the smallest microbes. The virus was beyond catching or seeing. With only poor optics at his disposal, Ivanovsky was not able to see

this mysterious being the size of a molecule. The more attractive his conjecture and the more it inflamed his imagination, the more difficult it was to convert it into a real scientific fact.

Fortunately, the insight of the investigator was sharper than his eyes. Ivanovsky realized that he had found a new infective agent.

This was a first-rate discovery. It was so far ahead of his times that no one argued. It wasn't scorned or refuted, it was simply ignored.

The Russian botanist Ivanovsky died unknown and viruses were forgotten.

Forty-five years later, Windel Stanley resolved the mystery of this offspring of the microbial family. Stanley at last got his hands on a virus: he isolated one in pure form.

Thus the pursuit of this elusive foe brought together four periods and four remarkable scientists—an Englishman, a Frenchman, a Russian and an American.

A test tube appeared on Stanley's laboratory table containing a crystalline powder. These were truly magical crystals that multiplied like live beings. For years they would sparkle behind glass, but once inside a living cell, they produced hosts of descendants, dangerous and infectious. Viruses passed through the finest filters, attacking tobacco leaves and leaving the same patterns as the mosaic agent which Ivanovsky had hunted.

What a marvellous coincidence: a live virus and a crystal. Truly a profound contradiction. How could a living being be a crystal? And what kind of a crystal is it that multiplies?

Actually, there was no contradiction. Simply biology had for the first time taken a big step forward towards uncovering the age-old mystery of the living. The question: "What is life?" took on new and concrete significance.

The virus became a problem concerning biology at large. The elusive virus suddenly brought researchers to the very heart of life—the protein molecule. Quite natural, for viruses contained one of the chief secrets of the molecular alphabet of living nature.

A Substance or a Being?

This was a peculiar molecule. The incomprehensible thing about it was its ability to reproduce, change its properties and transmit them to thousands of generations of descendants. One can understand an amoeba or even a microbe multiplying, but a replicating molecule was just too much. No biologist had ever encountered the like of it; nor, all the more so, had any chemist.

Both had long since divided nature into the living and the dead, which were separated by a chasm. Now here was a chemical compound that had dared to cross the gap and appropriate the specific properties of a living organism. This was an exciting challenge to biologists, for if they could get at the heart of this sudden coming to life of a half-dead crystal virus, they would be able to figure out the mechanism of reproduction. A virus which, on a sudden, awakens from a long "lethargic sleep" and multiplies enormously in

just minutes had, in their eyes, become the most elementary model of a living organism. Here was where biologists began studying the molecular foundation of life. Much time was to pass, however, before the enigma was actually approached.

At first the virus readily gave up the secret of its chemical composition. It was recalled then that all great things are simple. Only nucleic acid and protein were found. Simple? Yes, but that is where the simplicity ended. No one knew what the acid did or what the role of protein was. Virus was still "a thing in itself".

Then viruses were put under the electron microscope. Scientists were now convinced that they are very small, at times smaller than a protein molecule. Yet at other times a virus would surprise every one with its large size. Occasionally, it came out bigger than living microorganisms. It was then probably that someone got the idea of calling viruses borderline entities between the living and the dead.

I think it wise at this juncture to give some thought to the idea of the continuity of all elements of matter, from electrons, mesons, atoms, and molecules—the hardware of physics and chemistry—to the first rungs in the ladder of living life: proteins, viruses, microbes, Protozoa like amoebas and, finally, if you like, to animals, and man. And if you must have an analogy, the viruses are such diversified and complex things that it would be more appropriate to compare them to a whole undiscovered continent than to a borderline.

Who, today, is prepared to draw an arbitrary dividing line through life?

But this is more of a philosophical problem. We are dealing solely with facts, of which unfortunately there are too few. Sometimes it takes more to dig up an interesting fact than to formulate a dozen ingenious hypotheses. We were lucky—just the right kind of fact was finally unearthed. More correctly, it had long been known, but for some reason had never attracted attention.

No one had ever given much thought to the fact that a virus is barren in an ordinary culture medium where microbes are known to multiply with amazing rapidity. The virus was found to have one idiosyncrasy: it produced offspring only inside living cells. How was this strange whim to be explained? Why is a cell so inviting?

The attraction, it turns out, is food—proteins. Viruses are the greatest of all flesh eaters. They actually eat their prey alive. After an encounter like that, the cell, under an electron microscope, shows a hole drilled into it by a virus, which multiplies at a fantastic rate. Cells would have a hard time of it, if they didn't know how to repulse such devastating onslaughts. Usually, it is a life and death struggle.

Sometimes the virus perishes at the approaches to its goal, destroyed by solvents called lysines; at other times, they are dealt with severely by enzymes. Even when a virus gets past these foreposts of cellular defense, it comes up against a thick membrane which protects the cell from all comers.

This droplet of life, the cell, is definitely capable of standing up for itself. But then viruses too have a powerful weapon—enzymes that dissolve the cell membrane. When this is done, the virus finally reaches the food stores. Now it can take life easy, eating, multiplying and enjoying its existence. But then why is it so hesitant?

The cell is not finished yet, it turns out. Before entering the cell domain, a virus has to remove its "outer wraps"—a protein mantle pulled over the molecule of nucleic acid. Here, the cell itself helps the virus to divest itself of extra garments. For this job, the cell is believed to have special enzymes which work so thoroughly that the virus is stripped to its inner core of nucleic acid. The latter then plunges into the cell, where it finds food without end. What is more, the marvellous building machinery of the cell is now at the disposal of nucleic acid. The invading molecule feeds off stolen goods and feels at home almost immediately.

In a few minutes the virus has reproduced; minutes later a whole multitude of viral offspring have broken through the cell and are already out in search of food and shelter. And so we begin all over again.

But what actually happened in the cell interior while the molecule of nucleic acid was boss? And how did this chemical compound create the most complex and mysterious of creations of nature—a living being?

This is How

Finally, we seem to have arrived at the heart of the matter. I've already said that nature endowed nucleic acids with very special prerogatives—the mysterious process of reproducing cells, tissues, and organs. Life is in their hands. At all levels—from viruses to humans—these complex substances perform their unusually thorough work with amazing precision and rapidity. Out of rather simple organic compounds (amino acids) they assemble proteins—the big building blocks of any living organism.

The protein factory is perhaps the most ingenious and technologically sophisticated creation of nature: an automated production line which regularly turns out the goods that make life possible. No defective articles here. Millions of years have gone into developing a manufacturing technology of protein molecules that precludes the slightest error. If malfunction results in a faulty product, the organism straightway rejects the imperfect protein. But this is a rare occurrence. Discipline is extra-strict at the protein assembly line and is maintained by nucleic acids. They are the chief overseers.

The task of DNA is not an easy one. Twenty amino acids represent the raw material for the construction job. Out of these 20 building blocks, DNA has to erect the elegant and strong structure of a protein molecule. An assignment like this would keep a manmade chemical laboratory busy for years, yet DNA handles the job with ease.

Each one of the 20 amino acids that form the foundation of protein has a very specific place, and RNA, like an intracellular runabout, carries each block to the requisite site.

To produce protein, DNA distributes thousands of amino acids in accord with a strict plan. A phenomenal memory is needed to remember the arrangement of numberless amino-acid building blocks in the intricate architecture of a protein molecule. And DNA has that memory. It is built into the very structure of this complex and amazingly stable substance. The chemical structure of DNA embraces the entire plan of protein construction and, therewith, the chief features and properties of the future organism. Its molecules are peculiar messages of parents to offspring in which nature recorded in a special code the specific features of the stock. These characters are transmitted by DNA from generation to generation. If conditions are what they should be, DNA immediately starts up protein production.

Viral DNA is no exception. It gets into a living cell and switches all the machinery to suit its needs. Even the cellular power plant then goes over to supplying the protein factory of the invading virus. In a word, DNA is at home in the cell, where it loses no time in setting up production.

One minute, two minutes, three.... Researchers peer intently at this pulsating blob of life—simple yet magnificent as nature. The electron microscope enlarges the minute cell tens of thousands of times, while tagged atoms signal back information. Out of the depths of the madly rushing

fragments of salts, carbohydrates, pigments and ponderous fats and vitamins we see the first signs of emerging life—a viral protein has come into being. Not the whole virus yet, just the membrane, the protein mantle for the viral core. It is called a "doughnut" because there is nothing inside. To become a real virus, it has to fill up with nucleic acid. But where is so much to be had? There are hosts of doughnuts but only one molecule of DNA in the cell.

This molecule, it appears, has turned out over a hundred replicas all magically fashioned. The DNA molecule splits in half, and each half collects the needed portion out of the cell's amino acids. That results in two molecules of DNA. These then turn the same trick. Now there are four, then eight, and very soon over a hundred. Meanwhile the cell has prepared protein slipovers for them. These have to be pulled over the newly born molecules of nucleic acid. Then every DNA is enveloped in a tight protein suit and becomes a virus right before our eyes—the smallest particle of life has engendered a new life.

That is how the biologist first looked into the cradle of the living. Here, next to protein he found a molecule of the ubiquitous nucleic acid. And though the being generated by this bond was negligibly small and primitive, it became an excellent model for studying the cardinal laws of living nature.

Viruses are like newsmen reporting from deep inside the cell. They have brought to light a great deal about the marvellous protein transformations

that obey the slightest alterations in DNA structure. They have clarified a number of valuable secrets in heredity. Finally, the very existence, in a test tube, of hybrid viruses made up of different halves has corroborated a bold conjecture concerning the amazing chemical "memory" of nucleic acid, and its ability to unite with proteins to form infectious viral particles.

Recently, research scientists succeeded in isolating "bare" RNA from the tobacco mosaic virus and in wrapping around it a protein membrane taken from another virus. Nucleic acid was true to itself: plant leaves infected with this half-breed covered over with a mosaic pattern. Science had thus advanced from dissecting viruses to constructing them.

The reader may be wondering why these hybrids are needed when there are already so many microbes. The fact is that we need them because we have to learn more about the enemy if we want to conquer it. We don't even know very much about the influenza virus, which is constantly visiting us. Outwardly, it has been studied quite thoroughly, but its properties or character traits—as we have already seen—are still a mystery. When researchers prepare a vaccine out of the flu virus, they always run a risk, because the wild variety is not always like the domesticated virus. It has a magical gift for reincarnation. Changing the protein garb, it escapes unscathed. There are really no charms, of course. But neither is there any clarity.

How much easier it would be if biologists could read the peculiar chemical birth certificate

of the flu virus—nucleic acid, where, encoded, is the whole genealogical tree, the specific features and the extreme threat to man in its ability to change the structure of the membrane on a sudden, thus almost every time catching the immune forces of the body off guard.

Pure DNA could give quite some incriminating evidence about the virus, but first we must learn more about DNA. Without a membrane, it might become a fine producer of a strain of original "pure-bred" viruses, which are excellent raw material for any potent anti-flu vaccine. Then man's enemy, the infectious DNA, would become his friend.

So you see, breeding new kinds of virus is not harmful. Besides, there are about 200 different viruses in addition to the flu agent ready to attack humans. It is no easy job to get them into a straight jacket. But the task is a noble one.

Constructing living vaccines and interbreeding molecules makes a jeweller's work like that of a blacksmith, yet virologists have made some promising experiments in this new sphere.

A Tilt with the Invisible

When speaking of the latest victories of medicine, one invariably recalls infantile paralysis. "Recalls" is the right word because this disease has practically disappeared in the Soviet Union. The vaccine made of the poliomyelitis virus has firmly closed up all loopholes to its permanent hideout—the delicate tissue of the spinal chord.

This virus has lost its key and, homeless, it is doomed. And the longer its wanderings, the tighter will the nerve cells be shut and the faster it will die out.

The virus will naturally use every trick and all its capabilities for sudden metamorphoses. To survive, it may utilize the tested and tried method of his flu brothers, a change of membrane and a fresh assault. The fight may then flare up with still greater intensity. A tense and dangerous engagement where one opponent is all the time on the defensive, while the other is invisible and free to think up new devices and traps. Luckily, the situation has changed radically.

Medical scientists have now ceased taming the causal agent of polio, and have begun training it. Here's what happened recently. The virus was stripped to the bone, and put in a culture of monkey kidney tissue. There was no virus as such any longer, just a bare nucleic acid. Still it infected the monkey cells and produced profuse offspring. The experimenters immediately recognized their old friends, the polio agents.

The virus had not changed and had not lost any of its fighting qualities. Dressed, stripped, and dressed again, it was able to knock out an adult monkey. What do these clothe-changing experiments amount to?

They vividly demonstrate the role of nucleic acid, which is the chief bearer of the genetic and infectious properties of the virus. This is no longer abstract theory, but an experiment directly related to vaccines.

Only viruses with stable generic features are capable of producing a strong and lasting immunity. The organism uses them to test defense devices for future skirmishes with the real enemy. In these manoeuvres, the vaccine viruses are training targets, and must be as much like their wild relatives as possible. In a word, immunity training must take place under conditions as close as possible to the real thing. Which is understandable, for what good would come of a vaccine with the immune-forces of the body directed against a false foe or not trained enough to handle the real opponent?

Unfortunately, viruses are perfidious things. Multiplying on artificial food—colonies of living cells—a virus loses some of its inherent properties, like a predatory animal in captivity. An artificial virus like that is sometimes capable of sending the defense forces of the body off on the wrong track. To avoid this, scientists carefully select the best pedigree stock of domesticated infectious agents with marked species peculiarities. These chosen few are then used to prepare vaccines. It is a long and tortuous route, but so far the only one possible.

Now there seems to be another one. Viruses will be generated by the nucleic acid extracted from them. Like a matrix used to turn out newspapers, it produces pure-bred poliomyelitis agents. And it does it using raw materials that are cheaper than monkey kidneys. This is possible because nucleic acid, unlike its protein covering, exhibits no such specificity. With plain tastes it can manu-

facture viruses in all kinds of tissues, just so long as the needed enzymes and amino acids are present.

Building materials for the polio virus were obtained from pig kidneys, the amnion of a cow, even tumour cells. Nucleic acid turned them out just as diligently. Of course, the unrestrained savage differed from a vaccine like a wolf differs from a shepherd dog, but once it's bred, surely there is some way to domesticate it. That is a matter of time and persistence on the part of virologists. Hardly a day goes by without some fresh facts and first-rate discoveries.

Stanley, for example, performed an effective experiment. He isolated DNA from the causative agent of human polio, used it to inoculate a culture of tissues of an ordinary pond frog, and obtained a potent virus that energetically attacked a macaque rhesus monkey. I don't know whether frogs will ever replace monkeys, but these experiments already show that in the fantastic world of viruses and protein molecules, scientists no longer appear to be a perplexed guest, but an economical host.

Virologists have advanced to new lines. In the realm of molecular biology, they have at last struck an unbelievably rich vein of facts and are washing out valuable bits of new knowledge. And taking into account the present tremendous scale of anti-viral vaccination in the world, these facts are more valuable than gold, for the health and even lives of millions of people depend on them.

I have dwelt at length about the evil doings of viruses, but not all of them are enemies of the human race. Medics hope to utilize some of them against grave microbial diseases.

We have long known of the age-old hostility between viruses and microbes. Physicians hope to make use of it in their own interests. If it were possible to find or breed a strain of viral microbe-eaters, we would have a true and fast way of wiping out certain pathological bacteria in toto.

And not only bacteria.

Weeds, insect pests and even animals could fall prey to viral voracity. Take rodents, for instance. The thing is to find viruses that would take a liking to, say, thistle or marmots. Then these classical parasites would willy-nilly harness up to useful work. And would probably do it better than some chemicals. The point is that viruses are predatory beings, they can't stay outside a living cell for any length of time, and are always on the lookout for a place to settle in so as to survive. Now suppose a virus is offered a nice place like a mouse or hamster. These animals would not last a long time. Also a vegetarian virus parasitizing in plants would just as eagerly weed out fields of crops. In a word, agriculture is waiting for friendly viruses. There is hope that scientists will bring them out into the fields and farms and forests.

In certain places, Soviet biologists have already harnessed viruses to a job of nation-wide importance. In the Siberian taiga, for instance, they have been successful in wiping out the harmful gypsy-

moth larva that ruins millions of rubles worth of wooded areas.

This is definitely a gain, but viruses are undoubtedly capable of much more. They may be able to put an end to the rampant orderless proliferation of malignant tissue. Surely there should be, among them, destroyers of cancer cells. Indifferent to healthy tissues, these saviour viruses would destroy only the tumour. They would eat it up root and all. Or they might switch into the life cycle of the cancer cell and upset protein synthesis, thereby starving it to death. Then we will say that the virus has expiated its sins!

Studies in this direction are already under way. Thousands of varieties of viral particles will be tested on cultures of malignant tissues before a certain one finally exhibits the right kind of activity. This is an arduous and time-consuming job, but perhaps there is some way to speed it up. The price of delay has been calculated rather precisely: in the United States alone doctors uncover fifteen thousand cancer cases every week. Worldwide, it claims millions of lives. Where can we find a virus capable of saving at least half of these people?

Variability and deviation from parent features represent the chief hope of scientists in the search for the needed animal, plant, microbe. Viruses too are capable of reincarnation. This property is their trump card in the fight against human beings. Now it will be working for humans. And though viruses occasionally change on their own, as we recall the behaviour of the flu viruses,

radio-geneticists can make them change a lot faster.

X-ray irradiation can speed up the evolution of microorganisms, accelerate the rate of biological time. In this rapid, kaleidoscopic race and change of generations, scientists choose the most valuable strains. Thus we make use of microbes' dangerous peculiarity—variability.

To speed up time is an achievement; in one year, viruses live through tens, even hundreds of years. And still more can be done. Irradiation has so far altered the quantitative aspect by increasing the range of choice of experimental viruses. But biologists look farther, they want to learn to control the hereditary properties and alter characters at will—in a word, they want to create the living world anew, more reasonably, more rationally.

When this dream comes true (and there is every indication that it will), biologists will take any organism and according to a predetermined plan, by order, will fashion new beings. This will bring the biologist to the level of the physicist, who by then should have mastered controlled fusion. Anti-cancer investigations will undoubtedly profit, too.

But that is the future, what about today, right now? One of the first finds is adenoviruses, the causal agents of acute respiratory catarrhs. They unexpectedly dealt a strong blow at a culture of malignant tissue taken from a woman who had succumbed to cancer. They were immediately injected into the same kind of patient, right into the tumour. And to be doubly sure, they added

some in the general bloodstream. The viruses did a good job: very many cancer cells were dissolved and vanished, the tumour began to melt before the eyes of the doctors.

This was when the immunity effect (so undesired) went into action—the same one that protects us from microbes and viruses. Even from antitumour ones as well, unfortunately. Antibodies that neutralized the marvellous adenovirus quickly accumulated in the blood of the patient. The virus was bound and drained from the organism. Some of the regenerated cells survived, but the tumour was a malignant one!

Like transplantation of foreign organs, immunity here too played a foul role. But don't be in a hurry to put all the blame on it, for without this magnificent protective mechanism not one of us would live beyond childhood, so that cancer wouldn't even be known.

Now since people live to a ripe old age with the help of immunity, we should at least fix things so that immunity will not stop them from living still longer. The idea is to switch it off during treatment, inhibit the production of antibodies. Then viruses might complete their missions.

Medical researchers have found the needed brakes: cortisone and penetrating radiation. But don't be in a hurry, this is only the beginning. We can only wish them good luck.

Adenoviruses do not have a monopoly on cancer cells. It has been known for a long time that malignant tumours almost magically vanish in people infected with neurotropic viruses. Whether these

unexpected saviours operate via the nervous system or destroy the sick tissue on their own is not known, but medical workers recognized this blessing in disguise. For now they know that the contamination of certain species of cancer cells with specific viruses leads to the disintegration and elimination of the tumour. This fact, though not explained as yet, is especially valuable as a life-asserting force. It inspires faith in victory over this terrible evil, which today appears invincible to many.

Somebody said that science develops in a spiral. If that is so, then the turns must be close together at present. Yesterday's hypothesis has to be given up today and reorganized to fit fresh facts. In biology, like in living nature, there is a constant weeding out of the most valuable and stable facts. These, in turn, give rise to new ideas, conjectures, experimental plans.... That is how the great pyramid of knowledge grows, and at its summit lies scientific truth.

That is why, when the Soviet Academician Engelgardt expresses the interesting idea that malignant regeneration of cells is a peculiar deviation from the normal which can be artificially continued in order to return sick tissue to its normal state, and Windel Stanley suggests creating synthetic viruses (via hybridization of DNA molecules) capable of eating up a cancerous tumour, we realize that all this is not fantasy but just another turn in the upward spiral of science, another step towards the summit of knowledge.

Problem "X"

The world of the invisible is going through a revolution. Bacteria, pushed by antibiotics and chemical drugs, have given up their notorious leadership to all-penetrating ultramicroscopic beings. Viruses have become the microbes of the twentieth century. Their audacious and decimating raids are more costly than all microbial infections together, carrying off thousands and affecting the health of millions of human beings.

But all these heinous crimes pale before the suspicion that is hanging over viruses. They are accused of inciting normal healthy tissue to destructive uprisings.

The many-faced family of viruses may be hiding the instigators of malignant regeneration of cells. Though we haven't all the proof, there is much evidence. The sentence? I too am impatient to hear it. Severe and unbiased, in the name of science. But the judges are not agreed as yet. For half a century they have been arguing about filterable agents of cancer, and the end is nowhere in sight.... But judge for yourself.

A large number of tumour viruses have been isolated, even more than needed to prove their existence. The time is passed when, still unidentified, they existed mainly in the imagination of a few virology enthusiasts. There are no longer any ironical smirks when the discussion turns to viral sarcoma, leukemia, or even cancer. Over twenty-five species of tumours are known to be caused by viruses. But (there is always a "but")

it appears that the viral hypothesis of tumours has been countered in more ways than one; in fact, in so many ways that any other hypothesis would have long since collapsed. Yet this one continues to stand. What is it that holds it up?

Facts. They are stronger than words. So let us take a look at some. The arguments against: the main one, the trump card, is that no virus of human cancer has ever been discovered. No one has ever been able to extract it from a sick cell or see it under the greatest magnification.

That is a fact. Of the twenty-five species of virus neoplasms, only three affect human beings, and all these are benign at that. Viruses of cancer, sarcoma, leukemia affect only chickens, mice, rabbits, and possibly certain other laboratory animals. But not man. Does that mean that tumour viruses have by-passed him?

It seems hardly possible that they could have made that pleasant exception. Why the special privilege for humans? Nature never gives anyone any privileges. Its laws are the same for all. And if carcinogenic viruses are found in dogs, cows, deer, sheep, and finally, our closest relative, monkeys, what biological mechanism could gain a privilege for man? There is no such mechanism.

The virus of human tumours has not been found? So what? It is simply waiting for an Ivanovsky to discover it.

That roughly is the argument of the adherents of the viral hypothesis of tumours. We, however, are interested to see how they prove it in their laboratories. For instance, can human cancer be

made to infect a mouse? An experiment like that would be worth quite a few words.

The Soviet investigator Willyam Bergolts has performed such an experiment many times. This persistent experimenter has asked the same question of hundreds of experimental mice: Is there a virus in the blood of a human being afflicted with cancer of the white corpuscles—leukemia? The mice's answers were eloquent: a third of them got this terrible disease without receiving a single malignant cell. Blood plasma, ground-up bone-marrow tissue, or spleen tissue, just anything taken from human beings who had died of leukemia passed through the finest filters. Only ultramicroscopic cancer agents could have remained in the inoculative material. What are the causative agents?

The answer would appear to be simple: leukemia viruses of the patient. Unfortunately, this has not been proved as yet. Mice have their own leukemia, and the agent that causes it is still hidden in the cells. Who knows but the dormant virus might not wake up when mice are inoculated with the leukemia tissues of humans. That is hard to say. Let us leave it to the scientists. All the more so since we have encountered a new and remarkable property of carcinogenic viruses—a strange peacefulness due to sudden "sleepiness".

A disease-bearing virus sometimes lives for years in a cell without doing it the slightest harm.The cell gets used to the modest tenant and good neighbourly relations are established. All of a sudden the virus turns vicious. Almost as if

it had been waiting for its hour, it interferes in the synthesis of proteins and roughly upsets the genetic properties of the cell, making the latter sick.

What is this madness due to? Why did the peaceful virus suddenly attack, disrupting their quiet symbiosis? Finally, what occurs in the deep interior of the cell when such tragic events take place?

Lev Zilber, prominent Soviet virologist, was one of the first to give thought to these mysterious transformations. His idea was to seek the cause of the sudden wakefulness of the virus among carcinogenic substances. The choice was not accidental. For a long time, scientists have been watching carcinogens, which are believed to be the chief causes of cancer. The only trouble was that there were too many of them. What is more, they were soon joined by X-rays, ultraviolet rays, hormones, chemicals and many other things.

When a disease is found to have hundreds of causes, one quite naturally begins to think about some primal cause. The point is that all of these agents operate against the cell in some specific way, while the result is always the same—malignant regeneration. Perhaps the true explanation of the nature of cancer lies in the very diversity of theories and conjectures. It may be that investigators are constantly recording only the triggering mechanisms of tumour growth, accomplices in the murder of the cell, while forgetting the principal criminal, the virus.

But even the virus does not act on its own; it sits tight in the cell until given a signal from with-

out. Where is the beginning and where is the end of this entangled mess?

Only experiment can give the answer. Zilber conceived the following experiment. He took the carcinogenic substance benzanthracene and injected it into mice. As expected, it produced a tumour. Then he thoroughly ground up the diseased tissue and passed it through a porcelain filter. He then took a second group of mice and injected the filtrate and a harmless dose of benzanthracene. Several months later eighteen mice died from tumours.

Where did it come from, since even a microbe, say nothing of a cancer cell, can get through pores of porcelain?

Now a virus could very well have got through this barrier. Obviously, this was not a simple virus but a carcinogenic virus. Thus, it could easily be that benzanthracene did not by itself act on the cell, but via an intermediary, the viral agent of mouse cancer.

Professor Zilber's experiment launched a whole series of ingenious experiments. Carcinogens were followed by X-rays. Hardly anyone doubted that they could cause malignant regeneration of tissue. There had been too many sad cases. Yet here too the mice modified our views on cancer. When irradiated, they (as expected) gave an outburst of leukemia. But when the filtrates obtained from the tissues of leukemic animals were injected into newborn mice, the latter succumbed immediately. Not all of them, but in sufficient numbers to suspect the action of a virus.

Of course, no one ever rejected out of hand the tumour-generating force of carcinogens and radiation, but the argument around cancer took another tack. The adherents of the viral hypothesis had weighty facts. They now expected the same of their opponents. They asked them to demonstrate that there were no cancerous viruses in cells that had been regenerated under the direct action of carcinogens. Yes, we agree that the tumour developed after injection of benzanthracene, irradiation—all very true. However, you saw that the conditions of the experiment can be altered, while the result remains the same. There is probably no direct relation here between the apparent cause and effect. And if carcinogens precede a tumour that does not mean that they cause it. We are aware of the prologue and the epilogue of a single play, while the culmination takes place in the cell somewhere in between. And there is every reason to believe that a virus is playing a role, and not a small one either.

That seems logical enough, doesn't it? At any rate, the opponents have quieted down a bit. But the surprising thing is that the virus disappeared. In the cells of rabbit papilloma (warts, to put it simply), the virus was there for all to see. But when the papilloma regenerated into cancer, the virus vanished. Surely no opponent could have put the virus-theory people in a more difficult position than their own virus did.

Here is the picture. A virus is charged as being the principal cause of cancer, but as soon as a

benign tumour converts into a cancerous tumour, the virus disappears.

The tumour virus has turned out quite some conspirator. The virus did not vanish, naturally, but only lost its pathogenic properties for a time, turning from a vicious parasite into an inconspicuous and harmless hanger-on. Why this change in its mode of life?

The cell is to blame. As long as the cell is healthy, it is extremely hostile to any newcomer, and here is this stranger with designs on the factory of pure unique protein. Most likely the cell promptly generated protective substances capable of countering and blocking the unwanted guest, waiting for the right time to get rid of it. Without protein food and enzymes, the virus had to go underground. Here, disguised, it went undetected.

What happened to the cell?

A disaster! It had become cancerous. The virus went into hiding, while the tumour it produced changed and began to grow still faster. The diseased cells multiplied haphazardly, as if someone had upset the delicate mechanism of multiplication perfected over the ages. Apparently, that is exactly what took place. The illegal virus most likely maimed the cell's greatest treasure, nucleic acid. The virus switched its DNA into the pure pristine chemical that turns out proteins. The result was a monstrous hybrid and the cause of the malignant regeneration of tissue. The cell was no longer able to handle the situation. On the contrary, the virus took over and compelled

the cell to synthesize proteins in its own way. The cell obeyed and began to turn out protein goods of a totally different kind.

The cell is doomed now, for the new protein is so different from the usual kind that no regulators are able to bring it back to normal. The cell loses control and the tumour grows recklessly and rapidly. Now it is no longer of any importance whether the virus is still around or has vanished. The danger is not the virus, but the irreparable damage that it deals the genetic mechanism of the cell. When diseased, it cannot get out of the vicious circle, for the evil lies in itself.

But the greatest trouble is that all the defects are transmitted to the next generation. Each new generation of cells in a tumour receives a distorted DNA. Distorted and uncontrollable, it takes the wrong route. This continues until the organism dies. Isn't there some way of halting the reckless race to oblivion?

The viral hypothesis of cancer offers promise of new means capable of holding back the death-dealing onslaught of crazed tissue. The argument is not very involved. If particles of virus are indeed incorporated into the genetic apparatus of the cell and cause regeneration, then they must be kept away from the protein factory. In that case the cell might perhaps become normal again, for the disaster lies in the pernicious ties with the nucleic acid of the virus. If this union could be broken, the cell would return to a normal life.

That being the situation, cancer treatment should not consist in pursuing diseased cells (the

descendants come faster than we can follow anyway), but in destroying the genetic monstrosities induced by the tumour virus. Scientists call them additional genetic information, but the idea is the same. The main thing is to learn how to rid the cell of such additions and to get to understand its intricate relationships with the virus.

It seems to me that Professor Zilber's hypothesis opens up to oncologists a way that will sooner or later be the highroad of all cancer research—a study of the molecular foundations of the disease.

What Zilber has is as yet only an outline, of course, a working model of some future theory where analogies and comparisons occupy a rather large place. But underlying this hypothesis are established facts and, what is more important, it makes one search for new facts. The great Pavlov said that if there are no ideas in the head, there will be no facts to see. The idea is here, and so are the first fruits.

Remember the mice afflicted with human leukemia? They did not suffer in vain. We now have added support for the idea that their death might have been caused by a human virus and not a mouse virus. Nucleic acid obtained from tissues of people who had died of leukemia caused the very same disease in newborn mice. True, this fact had hardly sunk in when a new report arrived: nucleic acid taken from the leukemic mice themselves is also capable of reproducing cancer of the blood in healthy rodents. Again the old question: "Who is to blame?" But now it is being resolved at the molecular level. Experiments

continue and we now believe that in both cases the nucleic acid of a virus is one of the chief culprits.

This hypothesis has changed the approach to the problem of cancer. It has directed research into the depths of the diseased cell to delicate genetic mechanisms. The basic idea is to search for the cause within the cell, not around it. This thinking has lead to many fresh ideas and ingenious experiments.

Professor Graffi of the German Democratic Republic has attempted to inoculate a culture of kidney cells with nucleic acid extracted from a tumour virus. Eight times he extracted it and transmitted it from one colony of such "wild-growing" cells to another. On the ninth time, the DNA finally developed a membrane, again becoming a real virus and soon producing a tumour in an experimental mouse.

Investigations along these lines are being conducted in the Soviet Union too. Professor A. Timofeyevsky has been experimenting for quite some time with cell cultures. They grow in a glass test tube far from the mother soil and serve the viruses as an incubator with a ready supply of food. Timofeyevsky used these experimental cells to grow a new tumour agent discovered by the American woman-researcher S. Stuart.

This virus proved to be a universal worker, capable of affecting mice, rats, hamsters, rabbits; and not with only one tumour, but with twenty-three different tumours. Professor Zilber and his colleague I. Irlin injected this virus into a cul-

ture of young hamster cells and again produced a malignant regeneration—cancer in a test tube. The diseased cells grew and multiplied while the virus vanished. Again we suspect nucleic acid. The day may not be far off when just such a delicate laboratory experiment will disclose the infective agent of human cancer. At any rate, experiments with cell cultures will speed up the resolution of this agonizing mystery.

But the main thing is not here. A tumour in a test tube or in an experimental animal is only a model of the disease, frequently a model far removed from the original. There is never any assurance that it is due precisely to a transplanted virus. Many laboratory animals, as we have already seen, have their own specific inducers of tumours, and their tissues are appreciably different from human tissues. Tests might be made with cancerous properties of a virus on cultures of cells taken from healthy people, but there are great difficulties because malignant regeneration hardly at all shows up in any way.

Inoculate a human being with the filtrate of the tumour? Volunteers would probably be found for such an experiment. But the immunity mechanism would immediately go into action and the law of incompatibility of foreign tissue would come into force. No matter where you turn, the door is shut.

Where, along this enormous anti-cancer front, may we expect a breakthrough to the secrets of obstreperous tissue? Most likely in the laboratories of biochemists, where the protein composition

of tumour cells and the intricate chemical factory of cancer is under study.

In recent years, a number of secrets have been disclosed. Diseased tissue appears to have two foreign proteins: viral and tissue. Each taken separately is apparently capable of producing a strictly selective immunity in the animal: the viral protein with respect to the causative agent of tumours, the tissue protein with respect to transplantations of cancer cells. At any rate, half of the inoculated chickens remained unharmed after the injection of the death-dealing virus of sarcoma. And almost all of the experimental rabbits were invulnerable to the papilloma virus.

This was an exceedingly happy piece of news and a promising discovery. If the living organism is capable of protecting itself against tumour cells and viruses, then in time we may learn to immunize it artificially. For that we need the right proteins, but still more we need patience, because the substances that cause immunity are present in a tumour in amounts comparable to radium in uranium ore. It will probably be extremely difficult to obtain them from diseased tissue in a pure and concentrated form. The problem is all the more complicated by the fact that researchers do not yet know how to build up supplies of this valuable breed of protein. However, here too there seems to be some fresh light coming in.

Young biochemists Igor Abelev and Vladimir Tsvetkov of the Gamaleya Institute have found a

method for isolating the specific protein from a cancer tumour of the liver. And although the experiments were conducted on mice, and only a few hundredths of a milligram of protein were collected, these tiny bits of knowledge make the first real contribution to the age-old dream of artificial anti-cancer immunity. Thus, researchers are finding a way out in the depths of diseased tissue.

Cancer is still strong, it is still capable of strangling its victims. But it is no longer all-powerful. Surgeons, radiologists, chemical therapeutists have won out a number of times. Now immunologists and biochemists have joined their ranks.

Many countries are feverishly seeking for ways to protect human beings from these mad cells, to develop an immunity to this most vicious of diseases. We all want to believe that the time will finally come when inoculations against cancer will be just as common and successful as smallpox vaccination.

The analogy is not complete of course because cancer is not an infectious disease and its virus is not catching, but it is alien to the body like any other foreign protein. Which means that immunity can be built up—an anti-cancer immunity. That is for the future, what about now?

The treating of patients, naturally. Immunizing substances may save them from metastases and post-operational relapses of cancer. Most impor-

tant, however, they will help to produce serums that contain antibodies to cancer cells. By themselves, these antibodies are of course not able to control a malignant growth. Produced by a horse or sheep, they cannot remain in the body of the patient for a long time. But medical men are determined to outwit them by combining antibodies with a radioactive substance or a chemical, to utilize them as a transport agent that will deliver the medicine straight to its destination—the afflicted tissue.

Such labelled antibodies racing to tumours will help to locate them when hidden away in some distant part of the body. This means early and precise diagnosis and identification of cancer. In a word, there is much good to be expected of these interesting experiments. Here's to a successful completion!

I've been letting myself dream, but viruses are truly an endless topic for any writer. These ubiquitous agents enter our lives at every turn. And not only human beings. Domestic animals, birds, fish, even bees carry their yoke. Viral diseases afflict potatoes, cotton, fruit trees, tobacco.... There is rather weighty evidence that viruses are associated with rheumatism, and even the grave mental illness of schizophrenia; they are connected with lateral sclerosis of the spinal chord that paralyzes healthy young people, and probably have to do with many other obscure ailments. But it is time to finish. It is abundantly clear that viruses are extremely dangerous parasites. The war against them will go on until they are extermi-

nated completely. We have already seen the front line, let us hope to see the end of the war.

We have come to the end of our story. I would like to say a few words about the future. Not in the form of a long conclusion or deductions, or forecasts. Just a little talk about the very latest news. While I was writing this book, science continued to develop. New facts, conjectures, hypotheses were constantly coming in. Some of them compelled me to change plans and rearrange material. And still I was happy to be made to change things because living life does not tolerate fossilized formulas.

You recall, of course, how aggressive was the behaviour of newborn viruses when they left the cell. As soon as the cell broke open, they all scrambled out ready to attack man, a mosquito, a tobacco leave, anything—in order to survive. Their sole tactics is attack!

However, occasionally it has to be changed. The terrible fearless virus sometimes goes over to total defensive tactics, and even perishes in the face of a hostile onslaught. And not because of some antibiotic or a militant leucocyte, but at the hands of their own kin—another microbe.

Virus Hunters

Just recently, some brave spirits capable of counterattacking viruses have appeared among the great multitude of bacteria. They were detect-

ed by sheer accident in an old pond. These nameless warriors were destroying viruses with such a vengeance that one could think they were taking revenge for all their relatives. They literally tore the enemy to pieces. The scientist looking through his electron microscope saw a field of battle strewn with corpses. The victorious microbe did not even approach the enemy. It hit from a distance with a long-range weapon, most likely a special enzyme that dissolves the viral membrane.

It was hard to tear away from a spectacle like this—a real microbial insurrection. For the first time biologists saw a bacterium conquering a virus. In honour of this victory, it was called "virurumpens", or virus-tearing.

Scientists rejoiced, but not for the microbes. They hope to make these virus-eaters their helpers in the hard fight against infectious diseases. There is no reason why some abandoned pond might not have bacteria that feed on the viruses of polio, measles, encephalitis, and finally our most common foe, the flu. And if we don't succeed in finding them, we might, in time, breed them artificially—a special breed of "hunter" microbes and set them upon man's age-old enemy, the causative agents of viral infections. Then the fighting would be hot in the microbe kingdom.

This dream is not so illusory as it appears at first glance. It has deep roots in science. Mechnikov even had ideas of pitting microbes against microbes. He suggested continuously inhabiting the intestines with bacilli of lactic fermentation. He believed that these newcomers would displace

the "native inhabitants" (putrescent bacteria) and reduce the wear and tear of organs and tissues, thus prolonging life. Biologists have never given up Mechnikov's idea of an "induced antagonism" between microbes. Perhaps recent discoveries will help to make it a reality.

At any rate, medical scientists will be interested in the weapon of the new bacterium, its enzymes. This would be fine booty indeed. Physicians would aim it at virus diseases, against which sulfa drugs and even antibiotics are helpless. It is true that penicillin, streptomycin, terramycin and others, which are so successful in putting out the fires of grave microbial diseases, are helpless when dealing with a little and delicate virus. The reason is obvious: the virus hides inside the body cells away from the destructive action of antibiotics. The problem is to get it out.

To kill viruses, one has to destroy the cell, deprive it of enzymes that are used by viruses as food. But that would mean killing the host along with the unwanted guests. No, medics can't take that path. They are searching for (and with great difficulty are finding) relatively harmless drugs that strike at the enemy over the heads of their own troops. These "guided missiles" have halted no small number of bacillary ailments.

A bacillus is, of course, easier to hit than a virus. Bacilli are predatory beings that roam the body tissues in search of food, at the same time serving as shelter for viruses. Perhaps the enzyme of a warring bacterium might deprive it of its "diplomatic immunity". All the more so since

people need immunity against viruses, and not vice versa.

However, all this is still a dream, still in the imagination. Will I ever dream as far as reality? Yes, I think I will, at least before the sceptic who points to an "incurable" cold. The facts support this dream.

We want biologists to breed microbes that are ready to fight the infective agents of viral diseases, and fight to the death.

Ferenz Straub performed an elegant experiment which spells hope for a better future. He compelled bacteria to generate an enzyme on order. This was no common enzyme, but one against the all-powerful penicillin.

The stability of infective agents with respect to antibiotics is so sad and frequent an occurrence that such an experiment could hardly excite anyone. It is our bad luck that microbes themselves develop this unpleasant property very easily. But the most interesting thing is that here they acquired it by correspondence, for the experimental bacteria had never before met with penicillin. They trembled before it like many others of their kind. And suddenly total indifference. Where did they get the strength for such a strong rebuff?

DNA! These three magic letters have indeed wrought a revolution in biology. Straub isolated DNA from penicillin-stable bacteria and transferred it to a litter of microbes sensitive to this antibiotic. Henceforth they were no longer insensitive: the enzyme penicillinase produced by the

hybrid microbes protected them from the antibiotic in their very first encounter.

This experiment demonstrated what doctors often come up against nowadays. It is frequently difficult to cure pneumonia with penicillin, the drug that just a little while ago had helped perform flawlessly in such cases. They are grieved to see that similar friendly relations have been established between streptomycin and Koch's tubercle bacillus. And the worst thing is that a patient that has never used antibiotics is forced to give them up. Infected with a strain of stable bacilli, he is innocently deprived of the right to these marvellous drugs. Anyone who has used antibiotics on his own will know where the forefathers of these fighting microbial litters come from.

The point is that immunity develops not only in man with respect to a bacillary disease, but also in the bacilli themselves with respect to the drug used. Due to frequent encounters they get used to each other, occasionally helping each other out, the antibiotic contributing to microbial growth. A vicious symbiosis is established.

Straub's experiments are very important both scientifically and in an everyday sense. Over a hundred and fifty years ago, the noted Russian doctor Dyadkovsky once remarked that excessive use of drugs is far more harmful than not using them at all. And here is a modern experimenter, not an old-time clinician, with exact facts at hand corroborating this same reasonable idea. In a word, the discovery of the Hungarian scientist

is important, interesting and well worth pondering over.

But there is yet another aspect. It deals with the future. Scientists will not always be breeding penicillin-stable bacteria. The time will come for artificial breeding of useful microbes. It is hard to say how it will be done, whether by artificial selection, radio-genetics or cross-breeding, only time will tell. But there is no doubt that some bacilli will definitely be recruited for the war against infectious diseases. Then virus-tearing bacteria of all kinds will be allies of the human race instead of biding time in quiet backwaters. Biologists will isolate DNA from them and will possibly succeed in transmitting it to microbes that are always in the nasal passages and the pharynx.

Here, virus-fighting bacteria would be where they are needed. Another good place for them is the intestines, a common loophole for the polio virus, then again they would be busy on the mucous membranes of the respiratory tract where the flu virus is active. All these gateways of infection could be well guarded.

I am writing all this without regard for the very latest advances of science. They (and only they) enable us to picture the morrow. If in 1960 biologists succeeded in interbreeding, in a test tube, the DNA molecules of two dissimilar microbes and obtaining a peculiar molecular hybrid, haven't we reason to think that our hopes will come true in the distant yet close year of 1970?

I may be in error by a few years, but biologists

will forgive me, for their science is now orbiting with true cosmic velocity. Even a specialist finds it hard to keep up with its tempestuous race into the unknown. But everyone has a right to dream. Without dreams life would be cold.

There is hardly a mystery as intriguing and involved as the life of the living. Nature has done a tremendous job. The buildup of gigantic protein structures is the apex of its creative endeavours. Without resorting to cybernetics and mathematical computations, it resolved this exceedingly intricate problem with rare economy and originality. True, it took time to do the job—thousands of millions of years.

Nature's creative laboratory is where man will find the secrets of heredity and will learn how to control the growth of tissue and conquer man's greatest enemy—cancer.

Three scientists—biologist, chemist and physicist—have met at a busy intersection of science. Their job is to resolve a great riddle. For my part, I can only repeat after the poet,

What wonder of wonders
Is the living, is life!

To the Reader

Peace Publishers would be grateful for your comments on the content, translation and design of this book. We would also be pleased to receive any other suggestions you may wish to make.

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ABOUT THE BOOK

In this book the author relates in popular language about the latest attainments of biology and medicine, and about the future of these sciences.

The reader will learn about exciting operation on the heart, the mystery of cancer, the use of electronics in - medicine and about ingenious experiments aimed at extracting fresh information. He will get acquainted with viruses and the construction of the living cell, and will learn about the role of the new and rapidly developing molecular biology.

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Physician and writer Anatoly Shvarts had done much to popularize biology and medicine. He has written several widely-read books about Russian doctors and physiologists.

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